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ASTERIONELLA—ITS BIOLOGY, ITS CHEMISTRY, AND ITS EFFECT ON WATER SUPPLIES.

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[*Read March 8, 1899.*]

Asterionella is one of the microscopic organisms that cause trouble in water supplies by producing objectionable tastes and odors. It is common in Massachusetts waters, and is well known to many members of this association. Its recent occurrence in enormous numbers in the water supply of Brooklyn, N. Y., has given it an importance that it has not heretofore possessed, and its continued periodic occurrence in that city has been the occasion of the investigations here recorded.

Asterionella belongs to the Diatomaceae, a group of unicellular plants characterized by the possession of a siliceous cell wall. Further classification places it in the tribe Pseudo-Raphidieae and the family Fragilarieae.

A diatom cell, or frustule, is constructed like a box with an overlapping cover. There is a top and a bottom, known as the upper and lower valves, and sides, known as girdles, attached to each valve, the one fitting over the other as the cover fits over the sides of the box. The living matter inside consists of a thin protoplasmic lining, with a more fluid protoplasmic material which streams through the cell and bounds what are apparently empty

cavities; chromatophore plates, which give the diatom its brownish, or brownish-green color; oil globules; a nucleus, and probably a nucleolus. The living matter communicates with the outer world through minute openings in the cell wall, and sometimes through a conspicuous cleft, called a raphe, on the line of which are found nodules. Exteriorly, the diatom is usually covered with a gelatinous excretion.

According to the present method of classification, the various genera of diatoms differ chiefly in the shape and size of the cells, in the character of the raphe, and in the markings on the valves. Generally the valve-view of a diatom, the view looking directly at the cover of the box, gives the most characteristic shape; but in the case of Asterionella the characteristic feature is best observed in the girdle-view, the view looking at the connective sides.

The cells of Asterionella are long, linear, and inflated at the ends. In the valve-view they resemble the humerus bone in the arm, (Pl. I., fig. 5*a*); in girdle-view the ends are more expanded, but less rounded, (Pl. I., fig. 1*b*). Normally the cells are united by their extremities into star-shaped clusters, that give rise to the name, *Asterionella*. This star-like arrangement is seen in the girdle-view.

There is but one well-defined species of Asterionella found in fresh water, namely, A. *formosa* (Hassall), but many so-called varieties have been described, and some of these have been advanced by their discoverers to the rank of species. In our opinion, however, the differences that separate these various forms are too slight to warrant the multiplication of specific names, and it is questionable whether, in most cases, the variations in size and shape are sufficiently constant to mark well-defined varieties.

The typical form, Asterionella *formosa*[1], was observed in England about 1850. The frustules were described as varying in length from 55 to 80 microns[2]; as being more expanded at the basal end than at the free end, and as tapering from the base towards the extremity, (Pl. I., fig. 2*c*). The valves were said to be marked with striae 0.6 microns apart.

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1. Rev. Wm. Smith. Synopsis of the British Diatomaceae, London, 1853.
   Trans. Royal. Micro. Soc., London, 1860, p. 149.
   Dr. Henri Van Heurck. Synopsis des Diatomées de Belgique, 1885.
2. One micron equals .001 millimeter.

A. *formosa* var. gracillima[1] (Hantsch), (A. *gracillima*[2], Heiberg), is said to differ from the typical form by showing in the girdle-view a less expanded base and a more expanded extremity, and by being somewhat thinner in the valve view, (Pl. I., fig. *b*.) The length is stated as varying from 30 to 140 microns. According to some authorities the typical form, Asterionella *formosa*, is the most common, but recent observers agree that this distinction belongs to the variety gracillima.

Among the other varieties that have been described the following may be named, but they differ so little from the above that a detailed description is not necessary:

A. *formosa* var. subtilis,[3] Grun.

A. *formosa* var. subtilissima.[3]

A. *formosa* var. Ralfsii[4], Smith.

A. *Inflata*[5] Heiberg.

A. *Bleakeleyi*, W. Smith (Marine).

A. *notata*[6] (a variety of Bleakeleyi), Grun.

We have recently examined specimens of Asterionella from more than fifty localities in this country and abroad, and have found that all of them may be properly classed as the variety gracillima, but that there are many forms intermediate between the variety gracillima and the typical *formosa*.

The valves of most of the specimens observed were long, linear, with almost parallel sides, and with rounded inflations at the ends, as shown in Plate I., figs. 2, 4 and 5. In some cases they tapered slightly toward the extremity, and frequently there was a noticeable expansion in the middle. The inflation at the base was always larger than at the extremity, the latter being sometimes inconspicuous. The basal inflation, when large, was usually asymmetrical with respect to the major axis, as shown in Pl. I., fig. 5*a*.

In the girdle-view most of the frustules presented almost parallel sides, with a slight expansion in the middle and at the ends. The basal expansion was usually, but not always, larger than the other,

1. Van Heurck, *loc. cit.*
2. P. A. Heiberg. Conspectus Criticus Diatomaceae, Copenhagen, 1862.
3. Francis Wolle, Diatomaceae of North America.
4. Rev. Wm. Smith, *loc. cit.*
5. P. A. Heiberg, *loc. cit.*
6. Van Heurck, *loc. cit.*

and was never rounded except at the corners. The expansion at the extremity was sometimes rounded as in the valve view. Occasionally the frustules tapered towards the extremity. In many cases this was found to be due to the division of the cell, as shown in Pl. I., fig. 2*c*.

The lengths of the frustules varied from 27 to 78 microns, but the most common forms were about 55 microns long. The variations in length are shown by the following table:

TABLE I.

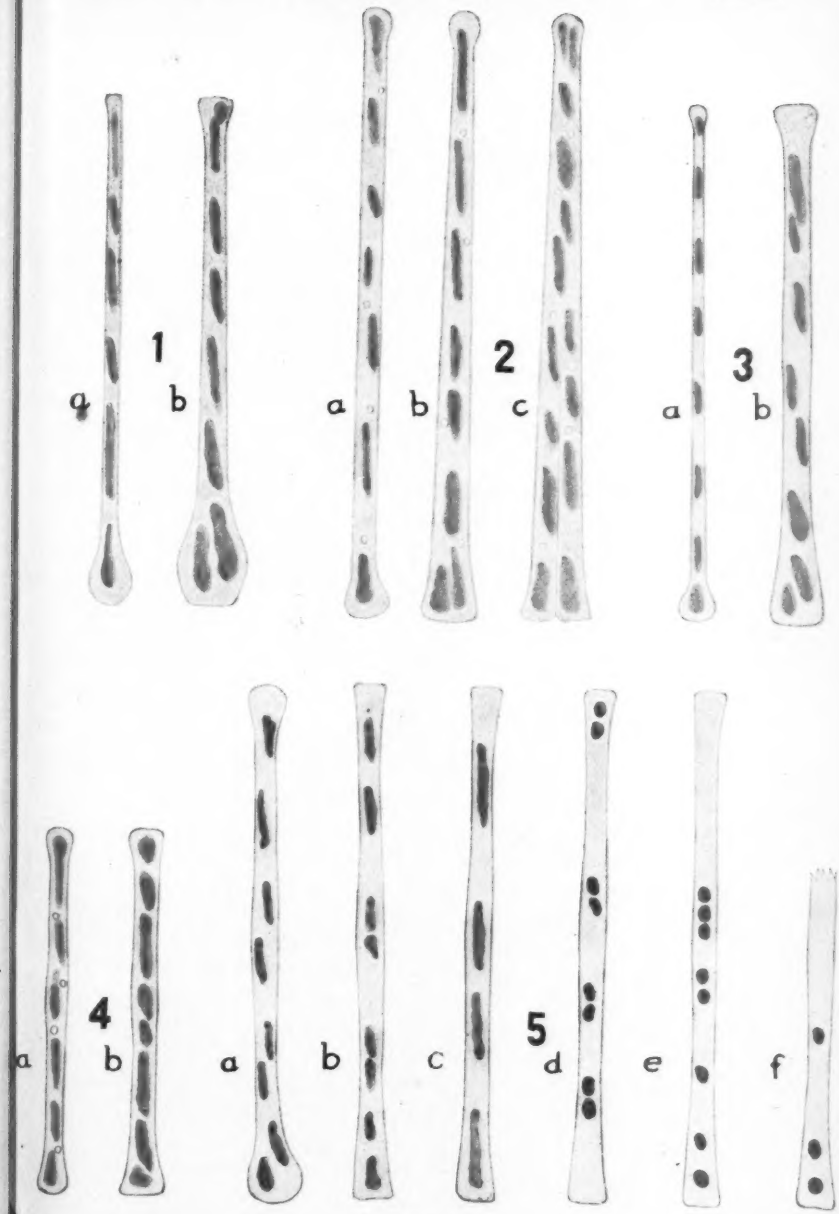
LENGTHS OF ASTERIONELLA FROM DIFFERENT LOCALITIES.

Locality.	Date.	Length in Microns.
Whitehall Pond	April, 1897	27 to 54
Ridgewood Reservoir	Nov., 1896	30
" "	Jan., 1898	40
Waltham Reservoir	Feb., 1899	36 to 45
"	Feb., 1896	53
Cape Pond, Rockport	Feb., 1899	48 to 62
Lake Cochituate	April, 1896	53
" "	May, 1891	67
Fresh Pond, Cambridge	Dec., 1895	57
" " "	Feb., 1899	63
Wenham Lake, Salem	Feb., 1899	65
Leaping Well Reservoir, South Hadley	Feb., 1899	72
Sandy Pond, Concord	Feb., 1899	78

It has been observed that the average size of Asterionella varies greatly in the same pond at different times, and that large and small cells are often present in the same sample of water.

The average width of the valves was found to vary from $2\frac{1}{4}$ to 4 microns, and was generally proportional to the length. The width of the basal expansion varied from $3\frac{3}{4}$ to 6 microns, and the width of the terminal expansion from $2\frac{1}{2}$ to 4 microns. In girdle view the width varied from 3 to $3\frac{1}{2}$ microns in the middle, from $4\frac{1}{2}$ to 8 microns at the basal end, and from $3\frac{1}{2}$ to 5 microns at the free end.

The cells were found normally in groups of eight, stellately arranged, as shown in Pl. II., fig. 1, but the number of cells in the groups varied from two to more than fifty. In many cases the cells occurred only in groups of four, as shown in Pl. II., figs. 2 and 3. The smaller forms in particular tended to form groups of four. Rarely the cells arranged themselves in a zigzag chain, as shown in Pl. II., fig. 3. The cells were held together at the corners



Asterionella.
Magnified 1000 diameters.

by a mucilaginous covering which surrounded the entire cell, but which was thicker at the basal end. It could be observed best by staining. Lumps of this mucilaginous substance are shown in Pl. II., fig. 4.

Asterionella multiplies by bi-partition. The separation of the two halves of the cell is observed first at the basal end, Pl. I., fig. 2*c*, but the division soon extends through the cell, as shown in Pl. II., fig. 4. The multiplication of the cells often gives rise to the spiral formation shown in Pl. II., fig. 5.

The method of reproduction of Asterionella is not fully understood. The only means of propagation known up to the time of this writing was that of cell division. Recently, however, we have observed that under certain conditions Asterionella forms spore-like bodies, or gonids.

In January, 1898, a mass of Asterionella was collected from Mt. Prospect Reservoir and left standing in a jar in the laboratory. It soon went through a process of decay and settled to the bottom—apparently inert. Microscopical examination showed that most of the cells had become separated from their neighbors, and were either empty or had their cell contents very much contracted. An examination made one year later showed that spore formation apparently had occurred. Minute bodies could be seen moving rapidly about inside the cells. In most of the cells they were eight in number and arranged in pairs, as shown in Pl. I., fig. 5*d*. In some the cell contents were collected in four long masses or in eight shorter ones—possibly a preliminary stage of spore formation. The spores, or gonids, were spherical or oval, from 1 to 1¾ microns in diameter, and of a greenish color. Many of them were motile, but the cilia could not be observed, though there were indications of their presence. In the fractured cells only a few spores were observed. (Pl. I., fig. 5*f*). These spore-like bodies were also seen outside the cells, but we have not yet had opportunity to trace their further development.

Asterionella is often covered with minute parasites. They are generally attached near the base of the cells where the gelatinous envelope is thickest. They apparently belong to the Choano-Flagellata, and have been described under the names of Salpingoeca[1]

1. Biolog. Centralblatt, Bd. 12, Sept., 1892, p. 505.

and Diplosiga[2]. Vorticella are sometimes found attached to Asterionella.

The subject of the occurrence of Asterionella in lakes and ponds needs but a brief recapitulation here, as it has been already discussed at some length before this association. The organism is known to be widely scattered over Europe and North America. It is not found commonly in running brooks, in streams, or in the stagnant water of ditches and shallow pools, but rather in large ponds, lakes and reservoirs, where comparatively clear water is stored. It has been observed in salt water, but it is essentially a fresh water plant—possibly not so much because of the chemical composition of the water as because the physical conditions necessary for its growth are not usually obtained in salt water.

The published reports of the Massachusetts State Board of Health show that Asterionella has been found at one time or another in nearly all of the surface water supplies of the State, and that in many of them it appears with great regularity and in comparatively large numbers. It shows a generally uniform horizontal distribution in a pond of uniform depth, but if there is a variation in depth in different parts, it is often more abundant in the vicinity of the deep places. Irregularly shaped ponds or reservoirs that have a well-defined stream entering at one end and an efflux at the opposite end also show irregular horizontal distributions.

It has been proved experimentally[3] that the rapidity of growth of Asterionella depends upon the amount of sunlight, and from this it follows that in vertical distribution the organisms should be most abundant near the surface.

Observation has shown that this is the case, though there is a nearly uniform vertical distribution through the actively circulating water above the thermocline[4]. This is shown in Table II. During the "periods of circulation" the vertical distribution is uniform throughout.

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2. Forschungsberichte aus d. Biol. Sta. zu Plon, Teil IV, 1894.

3. G. C. Whipple. Some Experiments on the Growth of Diatoms. Tech. Quar., Vol. IX, June-Sept., 1896.

4. The thermocline is that region in the vertical above which the water is in more or less constant circulation and below which the water is quiescent.

TABLE II.

VERTICAL DISTRIBUTION OF ASTERIONELLA IN LAKE COCHITUATE, MAY 7, 1891.

Depth.	Number per c. c.
Surface.	3,752
10 feet.	3,736
20 feet.	3,716
.....Thermocline.....	
30 feet.	1,784
40 feet.	456
50 feet.	536
60 feet.	178

One of the most interesting facts connected with Asterionella is its periodic seasonal distribution. Normally it occurs in surface waters in the spring and autumn. Growths seldom begin during the summer or winter, though such growths are not unknown. This spring and fall distribution is illustrated by Plate III., prepared from the records of the Massachusetts State Board of Health.

It was pointed out long ago[1] that these seasonal occurrences of Asterionella were directly connected with the phenomena of stagnation. It was shown that the most regular spring and fall growths occurred in those deep ponds where the stagnation phenomena were most pronounced; and that in shallow ponds, where stagnation was more common in winter than in summer, the spring growths were more constant than the summer growths. Continued observation has testified to the general correctness of the theory that growths of diatoms occur directly after periods of stagnation, and our recent discovery of what appears to be spore formation during periods of rest lends to it additional emphasis.

Spore formation may perhaps throw light upon the sudden appearances of Asterionella in water supplies. According to Pfitzer's theory multiplication by cell division results in the increase in the number of cells by geometrical progression, and experiments have proved that this law generally holds good, and that in many cases the increase in the number of cells amounts to about 50 per cent. a week. But this law does not satisfactorily explain those sudden developments where the Asterionella increase several hundredfold

1. G. C. Whipple. Some Observations of the Growth of Diatoms. Tech. Quar., Vol. VII, Oct., 1894.

in a few days. Such an increase may be possibly accounted for by such sporadic development as we have referred to.

The number of Asterionella found in the surface waters of New England seldom exceeds 5,000 per c. c., but this number may be sufficient to produce a noticeable effect upon the quality of the water. There are some ponds, however, where much larger numbers are found. In Horn Pond, Woburn, in the reservoirs of the Winchester Water Works, and particularly in Cape Pond, Rockport, the numbers occasionally rise to 10,000 per c. c., and in the last two mentioned places to 25,000 per c. c.

But it is in ground waters stored in open reservoirs where Asterionella attains its greatest development, and where it causes the most trouble. The experiences of Brookline, Waltham and other Massachusetts cities are familiar to the members of this association, but the recent troubles in Brooklyn far surpass them in magnitude.

The water supply of Brooklyn[1] is drawn from the western portion of the southern slope of Long Island, partly from the surface and partly from the ground. The system is a complicated one. There are 15 small storage ponds and 14 driven well stations. The driven wells vary in depth. Some are shallow and draw water from the upper strata only, while others pierce the clay bed and draw water from depths of nearly 200 feet. Of the ninety million gallons consumed daily nearly one-half are drawn from the driven wells. The watershed is very sandy and gravelly, so that a considerable proportion of the water that collects in the supply ponds has percolated through the ground. Therefore the Brooklyn water supply may be regarded as essentially a ground water. The waters from the various sources are collected by a conduit system that extends for 22 miles along the southern shore of the island. The conduit terminates at the Ridgewood pumping station, where the water is pumped into Ridgewood Reservoir, the main distribution reservoir of the city. This consists of three basins that have a total capacity of about 300,000,000 gallons. Their depth is 20 feet. A by-pass has been recently constructed around the reservoir connecting the force mains from Ridgewood pumping station

1. I. M. De Varona, History and Description of the Brooklyn Water Supply. A. S. Tuttle. The Brooklyn Water Works. Proc. Brooklyn Engineer's Club for 1896.

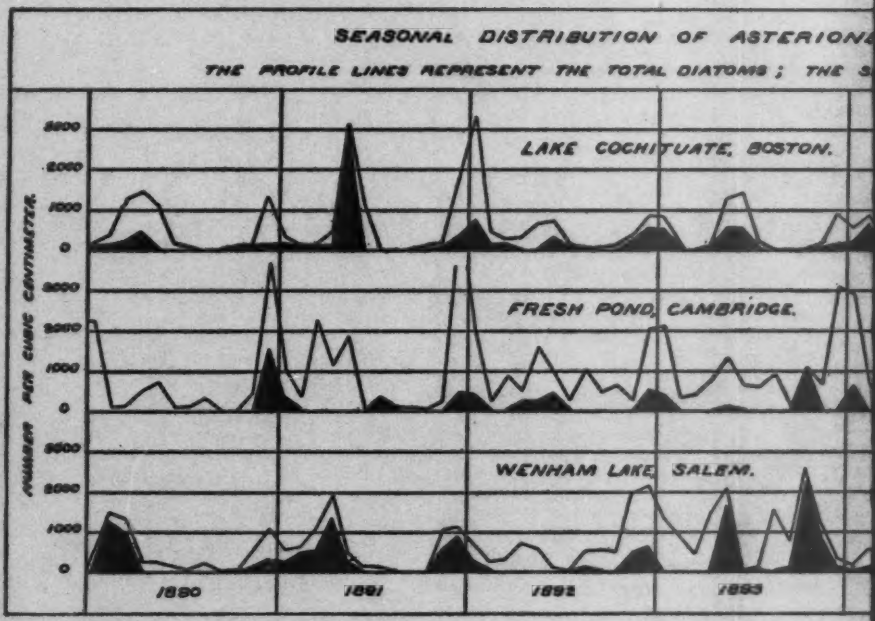
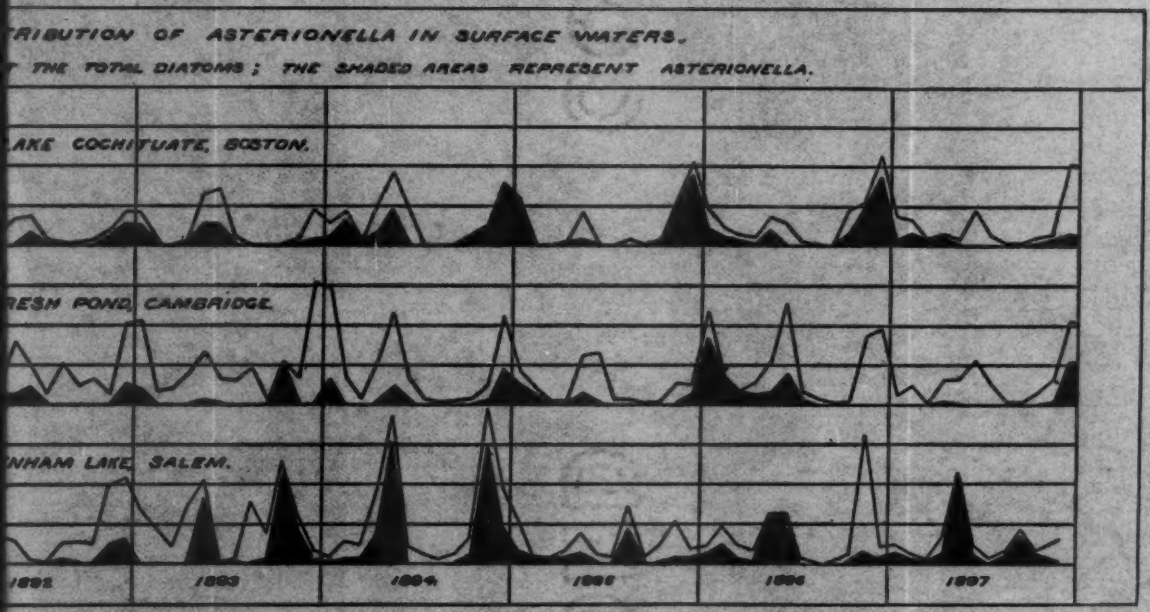

SEASONAL DISTRIBUTION OF ASTERIONE
THE PROFILE LINES REPRESENT THE TOTAL DIATOMS ; THE S
NUMBER PER CUBIC CENTIMETER.
3000
2000
1000
0
LAKE COCHITUATE, BOSTON.
FRESH POND, CAMBRIDGE.
WENHAM LAKE, SALEM.
1890
1891
1892
1893

PLATE III.


RIBUTION OF ASTERIONELLA IN SURFACE WATERS.
THE TOTAL DIATOMS; THE SHADED AREAS REPRESENT ASTERIONELLA.
AKE COCHITUATE, BOSTON.
RESH POND, CAMBRIDGE.
NHAM LAKE, SALEM.
1892
1893
1894
1895
1896
1897

with the distribution system, so that any or all of the basins may be isolated and the water pumped directly into the city mains without passing through the reservoir. A high-service reservoir is located at Mt. Prospect, near Prospect Park, in the heart of the city. In these two reservoirs we have on a very large scale a typical example of a ground water—more properly a mixed surface and ground water—stored in the light.

The Brooklyn water supply was originally drawn wholly from the small storage ponds referred to, but since 1883 there has been a constantly increasing use of well water, It was not until the well water had come to form approximately 40 per cent. of the supply that the microscopic organisms began to cause trouble. During the summer of 1896 these troubles became serious, and led to an investigation on the part of the Water Supply Department conducted by Prof. A. R. Leeds, and later to a similar investigation on the part of the Board of Health, carried on at a laboratory at Rockville Centre by Dr. Hibbert Hill and Mr. J. W. Ellms. These were followed by the establishment of the present laboratory of the Water Supply Department, known from its situation as Mt. Prospect Laboratory.

The investigations made by the Water Supply Department showed that the disagreeable taste and odor of the water was caused by the presence of Asterionella in the distribution reservoirs. The water as it was pumped into Ridgewood Reservoir was almost free from microscopic life, and had no disagreeable odor, though it possessed a slight vegetable taste due to organic matter in solution. The water as it left the reservoir, however, was clouded with minute particles that formed a sediment on standing and caused a very disagreeable odor described in the newspapers by adjectives innumerable. At this time there was no by-pass around Ridgewood Reservoir, and there was nothing that the Water Supply Department could do further than to draw as little water as possible from the basin worst affected, and to hasten the construction of the by-pass.

Recent studies have made it apparent that in August, prior to the final investigations made by Dr. Leeds, the offensive odors observed in the water were caused by Anabaena rather than by Asterionella, but in November and through the winter of 1896–7 the odors were due almost exclusively to Asterionella. During the past two years growths of Asterionella have recurred at intervals

in the reservoirs, accompanied by the usual odor, but the use of the by-pass constructed in 1897 has enabled the department to supply the city with water that has contained comparatively few organisms, and that has had little or no odor. In this use of the by-pass the department has been guided by the microscopical examinations made at Mt. Prospect Laboratory.

At times the numbers of Asterionella in the water of the reservoirs have been very high. For several weeks at a time they have been above 20,000 per c. c., and occasionally they reached 50,000 per c. c. Since the construction of the by-pass the numbers in the tap-water have seldom risen above 3,000 per c. c. For more than 90 per cent. of the time they have been below 1,000 per c. c., except in the small section of the city supplied from Mt. Prospect Reservoir, where the facilities for by-passing were not as perfect as at Ridgewood.

The odor produced by Asterionella varies in quality as it varies in intensity. At first it is simply aromatic; then it resembles the odor of a geranium plant; and with higher numbers it becomes strongly fishy. It is caused by a substance analogous to the essential oils. The minute oil-globules may be seen in the cells, usually from two to ten in number. The intensity of the Asterionella odor in water depends upon the number of the organisms present, but varies considerably according to their condition of growth. The odor is intensified by heat, by pressure, by mechanical agitation, or by whatever agency serves to liberate the oil-globules from the cells. It is difficult to find a scale upon which to estimate the intensity of the odor; but for convenience certain terms have been used, with the following approximate values:—A *very faint* odor is one which would not be detected by the ordinary consumer, but which could be recognized by the trained observer in the laboratory; a *faint* odor is one which would be detected by the consumer if attention were called to it, but which would not otherwise attract notice; a *distinct odor* is one which would be readily detected, and which might cause the water to be looked upon with disfavor; a *decided* odor is one which would force itself upon the attention and which might make the water unpalatable. The following observations on the intensity of the Asterionella odor were recorded at Mt. Prospect Laboratory during 1898:

TABLE III.

TABLE SHOWING THE NUMBER OF OCCURRENCES OF THE ASTERIONELLA ODOR OF DEFINITE INTENSITY WITH DIFFERENT NUMBERS OF ASTERIONELLA.

Intensity of Asterionella Odor.	Number of Asterionella per Cubic Centimeter.								
	0 to 500	500 to 1,000	1,000 to 2,000	2,000 to 5,000	5,000 to 10,000	10,000 to 20,000	20,000 to 30,000	30,000 to 40,000	40,000 to 50,000
None or Very Faint.	46	8	5	13	0	0	0	0	0
Faint.	0	3	3	5	6	3	0	0	0
Distinct.	0	0	3	8	19	6	3	2	0
Decided.	0	0	0	0	2	8	4	1	1

This table shows that of 72 samples in which no odor or a very faint odor was observed, 64 per cent. contained Asterionella below 500[1] per c. c.; of 20 samples that had a faint odor, 55 per cent. contained Asterionella between 2,000 and 10,000 per c. c.; of 41 samples that had a distinct odor, 46 per cent. contained between 5,000 and 10,000 per c. c.; and of 16 samples that had a decided odor, 88 per cent. contained above 10,000 per c. c.

We have made several series of experiments to determine more closely the relation between the intensity of the Asterionella odor and the number of the organisms present. Table IV represents the results of one series.

A sample of water that contained 46,000 Asterionella per c. c. was diluted with varying amounts of odorless re-distilled water, and the odors of the resulting mixtures were observed both hot and cold, at the time of preparation and after standing for several hours.

1. Many of the Asterionella found in the samples of this group were only empty cells.

TABLE IV.

TABLE SHOWING VARIATIONS IN THE STRENGTH OF THE ODOR OF ASTERIONELLA FOR DIFFERENT NUMBERS OF ASTERIONELLA.

Sample Number.	Number of Asterionella per Cubic Centimeter.	Odor.					
		Fifteen Minutes after Collection.		Six Hours after Collection.		Thirty Hours after Collection.*	
		Cold.	Hot.	Cold.	Hot.	Cold	Hot.
1	46,000	Decided	Decided	Decided	Decided	Decided	Decided
2	23,000	Distinct	Distinct	Decided	Decided	Distinct	Decided
3	11,500	Faint	Faint	Distinct	Distinct	Distinct	Faint
4	5,800	Very faint	Very faint	Faint	Distinct	Very faint	Very faint
5	2,800	None	None	Very faint	Very faint	Very faint	Very faint
6	1,400	None	None	None	Very faint	None	None

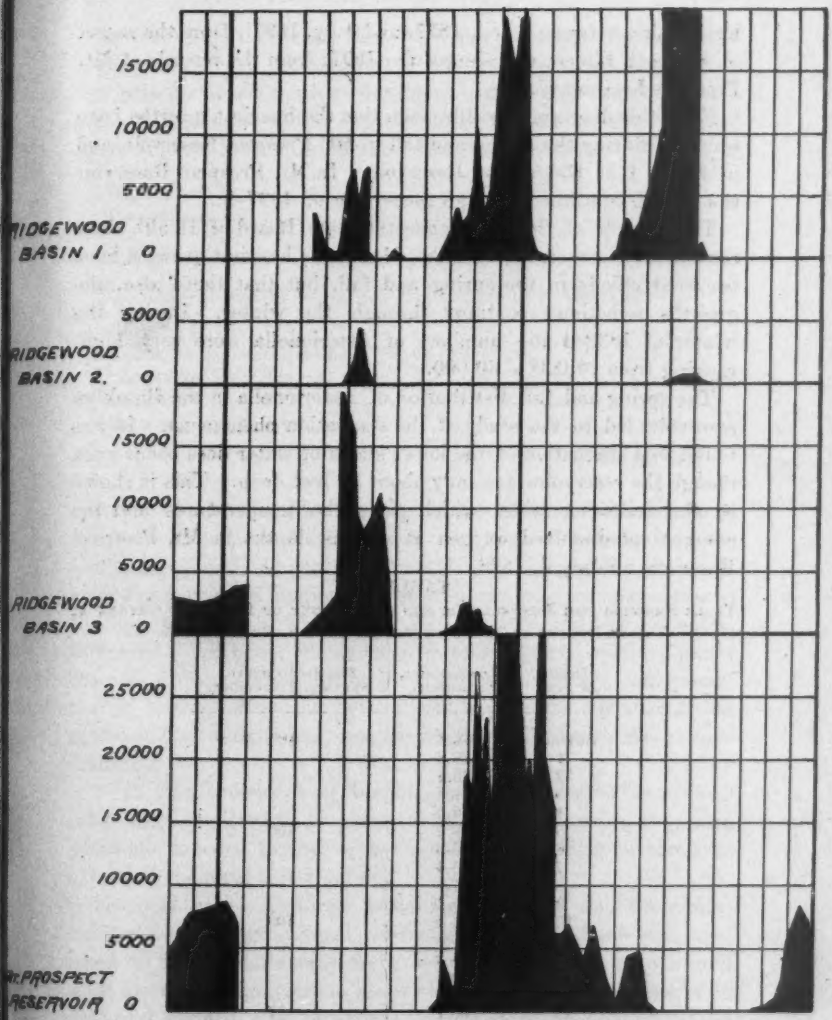
*After 30 hours the odor became modified by a moldy odor due to decomposition.

From these tables and from other similar observations, not here given, it has been found that the following relations between intensity of odor and number of Asterionella are substantially correct:

Odor.	Number of Asterionella per c. c.
None.	0 to 1,000
Very faint.	500 to 3,000
Faint.	1,000 to 5,000
Distinct.	3,000 to 15,000
Decided.	10,000 to ——

The laws that control the growth of Asterionella in open reservoirs where ground waters are stored have not been as well understood as in the case of surface waters, and for this reason the observations made in Brooklyn during the past two years are of particular interest. Briefly, these observations have shown that the same laws that govern the periodic occurrence of Asterionella in lakes and ponds hold true for small reservoirs where ground waters are stored.

The seasonal distribution of Asterionella in the three basins of Ridgewood Reservoir and in Mt. Prospect Reservoir from October, 1896, to December, 1898, is shown in Pl. IV. Between October, 1896, and February, 1897, the data were taken from the report of



NUMBER OF ASTERIONELLA PER CC.

BROOKLYN WATER WORKS.

Dr. Leeds; between April, 1897, and July, 1897[1], from the report of Hill and Ellms; and since July, 1897, from the records of Mt. Prospect Laboratory.

From this diagram it will be seen that the heaviest growths have occurred during the spring and fall in Mt. Prospect Reservoir, and in Basin 1 of Ridgewood Reservoir. In Mt. Prospect Reservoir the growth continued through the winter of 1897–8.

The records of the Massachusetts State Board of Health show that in the reservoir at Waltham, Mass., the heaviest growths have occurred chiefly in the spring and fall, but that there also, the growths sometimes continue through the winter. During the winter of 1893–4 the numbers of Asterionella were very high, ranging from 20,000 to 60,000.

The spring and fall distribution of Asterionella in the Brooklyn reservoirs led to the study of the stagnation phenomena. It was found that stagnation of the lower strata of water does occur even though the reservoirs are only about 20 feet deep. This is shown by the following table, which gives the temperatures and the amounts of dissolved oxygen at various depths in Mt. Prospect Reservoir on July 7, 1898:

TABLE V.

TABLE SHOWING THE TEMPERATURE AND THE AMOUNT OF DISSOLVED OXYGEN AT VARIOUS DEPTHS IN MT. PROSPECT RESERVOIR, BROOKLYN, N. Y.

Depth in Feet.	Temperatures, (Fahrenheit).	Dissolved Oxygen. Per Cent of Saturation.
Surface	76.8	100
1	76.8	
2	76.8	
3	76.3	
4	76.0	
5	76.0	100
6	75.5	
7	75.4	
8	75.4	
9	75.4	
10	75.4	100
11	75.4	
12	75 2	
13	70.3	
14	69.4	
15	68.1	67
16	66.8	
17	65.3	
18	63.9	
19	62.7	24
19½	61.9	

1. No observations were made at Mt. Prospect Laboratory during this period.

It was found, moreover, that there was a considerable deposit of organic matter at the bottom of the reservoirs, and that during the periods of stagnation, decomposition of this material takes place. A sample of the deposit at the bottom of Mt. Prospect Reservoir had the following percentage composition:

Organic matter	25.87%
Inorganic matter	74.13%
	100.00%

The mineral matter contained the following substances:

Silica, $Si O_2$	59.92%
Oxides of iron and aluminum, $Fe_2 O_3$ and $Al_2 O_3$	37.53%
Manganese oxide, $Mn O_2$	.50%
Lime, Ca O	1.15%
Magnesia, Mg O	.90%
	100.00%

It was found that the deposit at the bottom contained large numbers of Asterionella cells, and that these cells contained the bodies supposed to be spores. From this it is easy to conceive how, after the periods of stagnation, these spores, may become scattered through the water by the vertical May currents, and how the water, thus seeded and being well laden with food material obtained partly from the ground water entering the reservoir and partly from decomposing material from the bottom, and exposed to the stimulating action of the sunlight, may become suddenly filled with star-shaped diatoms.

With this knowledge of the biological and physical conditions controlling the growth of Asterionella in the reservoirs, it seemed desirable to learn further of its food supply. This involved an extended chemical investigation.

The food supply required by the higher plants has been carefully studied by agricultural chemists; the plants have been analyzed to find what elements were necessary for their growth, and soils have been analyzed to see if these elements were present in sufficient quantity and in a state capable of being assimilated by the plants; studies have been made also upon the relation of soils to the rotation of crops. Practically no investigations of this character have been undertaken for the microscopic organisms in

water, yet there is unquestionably as direct a relation between their required food supply and the mineral and organic constituents of water as there is between the required food supply of the higher plants and the mineral and organic constituents of the soil. If it is found by analysis that a microscopic organism contains a certain element in a certain amount, it is self-evident that the organism cannot grow in a water that does not furnish this element in sufficient quantity. This is true, however small the required amount of food material may be, and in the case of the microscopic organisms the actual amount of food required is indeed very small. With a better knowledge of the elemental constituents of the microscopic organisms and of the food material present in different classes of water, we shall be in a position to better explain why certain waters support growths of particular organism, and also to understand the reason for the "rotation of crops" among the lower forms of life. As a contribution to this knowledge we have begun with a chemical analysis of Asterionella.

In order to obtain its true analysis it was necessary to collect a large quantity of these diatoms, and at the same time to make sure that no other organisms or unorganized matter were present. The conditions for such a collection are seldom favorable, but in January, 1898, the water of Mt. Prospect Reservoir contained practically a pure culture of Asterionella, free from other organisms and from amorphous matter.

The apparatus used for collecting the Asterionella consisted of an eight-litre bottle, through the stopper of which passed a bent glass tube and the neck of a glass funnel. The funnel was covered at the top with silk bolting cloth No. 20, reinforced with a piece of strong white muslin. The water was led over the bank of the reservoir through a siphon-tube and allowed to pass through the apparatus as indicated by the arrows shown in the figure. With this arrangement, whatever heavy material was present settled to the bottom of the bottle, while the Asterionella, held back by the cloth, collected in the funnel itself. After a flow of 24 hours the Asterionella were removed from the cloth and funnel in a highly concentrated state and dried at 100° C. This process was repeated for several days until a sufficient amount of the substance was obtained. It will be seen that this apparatus may be used for collecting pure cultures of other microscopic organisms. Tap water is not always

available and it seldom contains the organisms in pure cultures and in as good condition as in the reservoir. The Asterionella thus collected in mass had a dark brownish-green color which changed to a light green on heating. It was of a gelatinous consistency and possessed so strong an odor that it permeated the whole room in which it was kept.

The chemical analysis was carried on as follows: The carbon, hydrogen and oxygen were determined by organic combustion; the nitrogen by the Kjeldahl process. The total sulphur was determined by treating with strong, chemically pure caustic potash, evaporating, neutralizing with hydrochloric acid, and precipitating with barium chloride after the separation of the silica. The total phosphorus was determined from an aliquot part of the same solution. The mineral analysis was made according to the usual scheme when phosphates are present. It was found that the organic phosphorus remained behind in the ash, so that it is contained in the figure given for inorganic phosphorus. The results of the analysis given in the following table represent the averages of many determinations.

TABLE VI.

PERCENTAGE COMPOSITION OF ASTERIONELLA.

Carbon	18.78%
Hydrogen	4.20%
Nitrogen	2.20%
Sulphur	0.61%
Oxygen	16.69%
Total Organic Matter	42.48%
Silica, ($Si O_2$)	49.48%
Iron Oxide, ($Fe_2 O_3$)	2.32%
Lime, (Ca O)	1.45%
Magnesia, (Mg O)	1.26%
Potash, ($K_2 O$)	1.22%
Manganese oxide, ($Mn_2 O_3$)	0.84%
Phosphate, ($P_2 O_5$)	0.67%
Sulphate, ($S O_3$)	0.38%
Total Inorganic Matter	57.52%
	100.00%

The ultimate organic analysis, as shown by the above figures, offers but little scope for discussion, inasmuch as there are no similar analyses of other microscopic organisms with which it may be compared.

In the case of the nitrogen, however, we have a few determinations with which comparisons may be made, as is shown in the following very incomplete list:

Diatomaceae—		
Asterionella	2.2*	% Nitrogen
Chlorophyceae—		
Spirogyra	4.5	" "
Cyanophyceae—		
Anabaena	9.6	" "
Clathrocystis	8.3	" "

*If the silica of the organism is disregarded, this percentage becomes 4.3.

These decided differences in the percentage of nitrogen in the various classes of organisms suggest differences in the amount and kind of food material required, but we have as yet too few comparative data to draw any definite conclusions.

The most important feature of the analysis is the high percentage of mineral matter, which amounts to 57.52 per cent. of the dry weight of the organism; 49.48 per cent. of the dry weight is silica that occurs in an absolutely pure state as the cell wall. This high percentage of mineral matter renders the cells of diatoms heavier than those of most plants. From a number of observations upon the weight and number of Asterionella present in a certain quantity of water, we have calculated that the average weight of one Asterionella cell is .00000000036 gram.

From this weight we have calculated the amounts of the various mineral constituents that a water must contain in order to support a growth of 10,000 Asterionella per cubic centimeter. This number was selected because it is sufficient to give a distinct odor to water. The results, expressed in parts per million are given in the following table, together with the analyses of certain surface and ground waters:

TABLE VII.

Table Showing the Relation Between the Constituents of Asterionella and those of certain Ground and Surface Waters.

Expressed in parts per million.

Constituents.	Asterionella 10,000 per Cubic Centimeter.	Surface Water. Average Composition of Boston Water.	Mixed Surface and Ground Water, Brooklyn Water.	Shallow Ground Water, Spring Creek, New Wells Brooklyn W. W.	Deep Ground Water, Roxbury Wells. Average of 21 Samples.	Shallow Ground Water, Cambridge, Charlestown and Boston Wells. Average of 31 Samples.
Albuminoid Ammonia	——	.188	.135	.035	.022	.017
Free Ammonia	——	.025	.040	.010	.011	.379
Nitrates	——	.250	.174	5.08	5.95	‡.041
Total Organic Nitrogen	.079	†.376	.270	.070	.044	.034
Silica	1.780	3.04	7.59	15.16	15.31	18.14
Ferric Oxide	.083	*.75	* .18	*.34	.27	1.61
Lime	.052	6.45	13.99	47.70	61.3	78.3
Magnesia	.045	1.60	8.46	24.32	26.8	82.3
Potash	.043	.92	——	1.84	——	——
Soda	.000	5.00	——	13.90	——	——
Manganic Oxide	.030	——	——	——	§	‖
Sulphates	.014	4.58	7.43	1.84	36.5	65.6
Total Solids	3.600	48.5	93.6	212.0	435.0	1578.0

‡Of the 31 samples averaged, 18 contained no nitrates.

†Estimated as double the albuminoid ammonia.

*Includes oxide of aluminum.

§Of the 21 samples averaged, 10 contained no manganese.

‖Of the 7 samples analyzed, 3 contained no manganese.

It will be seen from this table that if a water holds 10,000 Asterionella per c. c., it must contain 1.78 parts per million of silica, and it follows that in order that the Asterionella may develop to that extent, the water must contain at least that amount in solution and in a condition capable of assimilation. It is more than probable that only a portion of the silica present in most waters is in such a condition that it can be utilized by the diatoms. As a rule ground waters contain higher percentages of silica than surface waters and hence they are capable of supporting larger growths of diatoms. In the table, for example, it will be seen that the Boston water, a surface water, contains 3.04 parts of silica per million, while the Brooklyn water, a mixed surface and ground water, contains 7.59 parts. These amounts of silica alone would limit the growth of Asterionella to 17,000 per c. c. in the case of the Boston water and 41,000 per c. c. in the case of the Brooklyn. In the Brooklyn water the amount of silica is often greater than this. Its amount depends chiefly upon the proportion of ground water used. The water from the Spring Creek shallow wells contains about 15 parts of silica per million, and that from other wells, 23 parts per million.

But any of the other mineral constituents may limit the growth of Asterionella in the same way. For example, Asterionella apparently requires a definite amount of manganese, an element that is often lacking in water. The records of the Massachusetts State Board of Health show that out of 40 ground waters in which manganese determinations were made, 19 contained no manganese at the time of analysis. Observations prove that this element is a variable quantity in water. It is known to be present in both the Boston and Brooklyn waters, but in the case of the analysis quoted the determinations were not made.

As a rule most waters contain lime, magesia, potash and sulphates in sufficient quantity to support heavy growths of diatoms, but iron, manganese and silica are sometimes lacking in the required quantity.

Nitrogen is an important constituent of the food supply of Asterionella, although its percentage is not large. It is supposed that in order to be utilized it must be in the form of nitrate, though it is possible that free ammonia may be made available as food under certain biological conditions. It is probable that

growths of diatoms are often limited by the amount of nitrates present. Thus it is evident from Table VII that 10,000 Asterionella per c. c. could not grow in the water represented in the last column, unless some of the free ammonia present were changed to nitrate through bacterial action.

This knowledge of the nature of the food required by Asterionella throws new light upon its periodic seasonal occurrence. During the stagnation periods the diatoms that lie in large numbers in the decomposing matter at the bottom of the reservoir. After stagnation ceases, the vertical currents carry them to the surface and hold them within the influence of the sunlight, where, under its stimulus, they develop. Meanwhile the water has increased its capacity to nourish them. During the stagnation periods the water at the bottom has been absorbing the necessary mineral and organic constituents, and at the overturning they are brought up, modified by bacterial action, and put in a condition such that they can be utilized as plant food. This action may occur in reservoirs where ground water is stored as well as in lakes and ponds.

From these facts it follows that we have a partial remedy for the occurrence of Asterionella in ground water exposed to the light. Modern engineering practice has taken strong ground that well waters should be stored in the dark, and this position is emphatically the right one. But it is not always possible to cover existing reservoirs. It seems probable, however, that if these reservoirs are frequently cleaned, the troubles from Asterionella may be very much alleviated. If the organic matter is not permitted to collect and decompose on the bottom of the reservoir, and if the organisms are not permitted to sporulate there, there is good reason to believe that such *heavy* growths of Asterionella as have been recently observed in Brooklyn[1] will not occur.

Summary. In this paper we have endeavored to establish the following facts:

1. That the common form of Asterionella is that known as A. *formosa* var. gracillima, but that great variations exist in size, shape and arrangement of the cells.

2. That Asterionella is widely distributed in nature, and that it

1. Basin 2 of Ridgewood Reservoir has been recently emptied and cleaned, and it is intended that the other basins shall be cleaned in the near future.

is found chiefly in lakes, ponds and reservoirs, where comparatively clear water is stored.

3. That its growth in surface waters occurs chiefly in the spring and fall, and is intimately connected with the phenomena of stagnation.

4. That it develops most vigorously in open reservoirs, where ground water is stored, and that its growth in these reservoirs follows the same laws as in surface waters.

5. That its odor varies in character from geranium to fishy, and that under favorable conditions 3,000 Asterionella per c. c. may impart to water an odor that will be easily recognized by the consumers.

6. That it forms what appears to be spores during periods of rest, and that this sporulation takes place at the bottom of reservoirs during periods of stagnation.

7. That its sudden developments after such stagnation periods may be due to the germination of these spores.

8. That its food supply is a definite quantity, and that the organism will not grow in a water where any one of its constituents cannot be obtained in sufficient quantity and in a form capable of assimilation.

9. That the food elements most likely to be deficient in water are silica, manganese, iron and nitrates.

10. That if reservoirs are not kept clean, stagnation tends to increase the amount of food material in the water, and that the increased amount of food material after the stagnation periods helps to explain its periodic seasonal occurrence.

11. That it is desirable that ground water should be always stored in the dark, but that it is possible to alleviate the troubles due to the growth of Asterionella in open reservoirs by keeping such reservoirs free from deposits at the bottom, thus preventing them from becoming heavily seeded with spores, and also preventing a material increase in food supply.

12. That where the use of open reservoirs for the storage of ground water cannot be avoided, they should be so designed that they may be cleaned whenever necessary, and that they may be temporarily isolated from the system whenever growths of organisms make the water unsuited for use.

In conclusion, we wish to acknowledge our indebtedness to Prof.

Charles Wright Dodge, of Rochester, N. Y., Prof. C. Schröter, of Zurick, Switzerland, and Miss Lilly Miller, assistant biologist of the Massachusetts State Board of Health, for furnishing us specimens of Asterionella from many localities; and also to express our thanks to Mr. Robert Van Buren, C. E., chief engineer of the Department of Water Supply, Brooklyn, N. Y., for permission to quote from unpublished reports.

DISCUSSION.

PROF. SEDGWICK. Mr. President, I have enjoyed, as I have no doubt others have, this paper. It seems to me that it outlines practical work, which is to find out what the organisms are, what they need to live upon, and then to starve them out. That is what the paper proposes to do.

With regard to the very important statement as to the discovery of spores, I think these gentlemen, the authors of the paper, must not be disappointed if people are a little slow to accept their results, because they are so revolutionary. I think no one has ever claimed the existence of spores in diatoms—at least this sort of spores—and until they can see some of the spores developed into corresponding diatoms, they must anticipate a certain amount of skepticism on the part of botanists and biologists. And I say this without intending any criticism of the work. I have no doubt they really believe it to be true, and I have no doubt it appears to be true, and I wish I could say I have no doubt it is true. But it is so new that I think I shall have to go slow before positively accepting it. These would be virtually zoospores, and there is no intrinsic reason why they should not exist or why they could not exist. I think, however, that the argument of the authors for their existence, that such existence would explain the rapid growth of diatoms, requires a little reflection. It seems to me if you took one of these things, only a twenty-five thousandth of an inch long, which is the size given, and set it to work to build up its own substance several times over, and then to prepare the silicious case in which that substance must grow, it is going to take quite as long, if not a little longer, than to divide up a lot of ready-made diatoms lengthwise in the ordinary way in which we suppose that they grow. I may be wrong, but it seems to me that the argument may be subject to criticism, judging by the ordinary rate of growth of micro-organisms.

However, it is a very interesting theory, and it is in the right line. These were resting diatoms; there was every reason to suppose that the protoplasm should take on some such state as they have described, and I am prepared to accept it, provisionally; but I think that botanists generally will go a little slow until these gentlemen, the authors, see one of these zoospores actually settle down and build a case for itself and become an Asterionella. I say this simply because I have been caught in that trap myself. On one occasion I saw a mould, a Penicillium, as I thought, producing yeast. I went ahead and announced the fact, and was afterward corrected by a very eminent botanist, and very properly so, because I hadn't watched the whole chain of events clear through, and he objected on that ground. However this is a minor point. The gentlemen are entitled to praise, it seems to me, for their careful investigation. Whether they have hit it right in every instance doesn't matter. It is keeping constantly at work, which they are doing, and attempting new methods of study, which will give us eventually good results, some of which they have already obtained. For their chemical analysis alone it would have been worth while getting them on here from a point very much more remote than New York. It is no small triumph to be able to know the chemical composition of a diatom, or to be able to estimate its weight, as these gentlemen have done.

The paper is carefully prepared, it is original, and it seems to me it is entitled to high praise, and in what I have said I do not intend any hypercriticism. It is only a word of caution, because I know how skeptical the ordinary botanist will be of such a fundamental and revolutionary discovery of spores as the one here announced. I think our proper attitude is to wait, as in all other discoveries, for confirmation. This association may well congratulate itself on being able to see the silica derived from a given number of diatoms and to have percentages stated, so that it is possible to prevent their growth by keeping the silica, manganese and the like out of a water supply. The table which shows how many diatoms it takes to make an odor is a very valuable and practical one, because if we find 500 diatoms in a cubic centimetre we need feel no alarm, but if they are mounting to 1000 or more then it is time to beware. Here is a practical point of the utmost conse-

quence, it seems to me; and there are are many other theoretical and scientific points in the paper also of great consequence.

THE AUTHORS. In reply to Prof. Sedgwick the authors wish to disclaim any originality for the discovery of spore-formation in the Diatomaceae, but simply to record the fact that these spore-like bodies are to be found in the genus Asterionella, just as they have been already found in a few other genera. Regarding the development of diatoms through the agency of spores, diatomologists are now divided into two hostile camps and the question at the present time is an open one. Our observations, so far as they have extended, seem to favor the spore theory. Some recent articles on this subject are the following:—

De la reproduction des diatomees. J. Newton Coombe.
Annales de Micrographie. Jan. 1898. p. 10.

Les spores des diatomees. Castracane.
Annales de Micrographie. Jan. 1898. p. 30.

Des spores des diatomees. P. Mieuel.
Le Diatomiste. Vol. II, No. 26.

The Reproduction of Diatoms. J. Newton Coombe.
Journal of the Royal Microscopical Society. Feb. 1899.

CHLAMYDOMONAS IN SPOT POND.

BY FREDERICK S. HOLLIS, BIOLOGIST, AND HORATIO N. PARKER, ASST. BIOLOGIST, METROPOLITAN WATER WORKS.

[*Read March 8, 1899.*]

The occurrence of Chlamydomonas is of special interest, as it is the first time during our investigations that we have found it in large numbers, and our examinations have shown that it imparts an unpleasant taste and odor to the water. It is, we believe, the first record of trouble caused to a water supply by its presence. As is the case with all such growths, the cause must be sought in the nature of the water in which the growth occurs. Spot Pond is a natural pond situated in the Middlesex Fells, in Stoneham, Mass. The original elevation of the surface was one hundred and forty-two feet, the present elevation one hundred and fifty-two feet, and the present capacity seven hundred and sixty-four million gallons. The water is thirty or more feet deep in the southern part of the pond, while much of the northern and northwestern part is little more than shallow flowage. The nature of the water which it receives is influenced by swamps situated to the north of the pond, and also by thick deposits of loam and mud at the bottom of the pond, which in some parts of the shallow flowage has a depth of twenty-five feet. This mud is to be removed and the pond otherwise improved for use as a storage reservoir of the Metropolitan Water Works. For a water which must be derived to a considerable extent from springs, the color is dark; the average color of the water of the surface for 1898 being 0.46. The water at the bottom of the pond was stagnant from the last of June until the overturn of the water during the second week of November, reaching a maximum color of 2.00 soon after the middle of September. The water was again stagnant within two weeks after the autumn overturn, and reached a color of about 1.50 during the last of January and first of February.

Microscopical examinations of samples of water from the surface, mid-depth and bottom of this pond have been made regularly since the first of March, 1898, which showed the presence at all times of a considerable growth of microscopic organisms. Diatomaceae reached a maximum spring growth in May of 1339 standard units per c. c., as an average for the surface, mid-depth and bottom. Chlorophyceae were present in small numbers throughout the period. Cyanophyceae were present throughout the period and of importance from the last of May until late in September, with a maximum growth in August. Infusoria were present in considerable variety and numbers throughout the period. The most important growth occurred in the spring, and was composed mainly of Peridinium and allied forms. The growth of Chlamydomonas appeared about the middle of August, at a time when the water had an unpleasant taste and odor, due to the decomposition of a growth of Anabaena. As this taste and odor resulting from the decomposition of the Anabaena decreased, a distinct taste and odor was observed which varied as the number of Chlamydomonas increased. The taste and odor were intensified by heating the water, and varied with the freshness of the sample and the relative number present. Small numbers of Chlamydomonas gave to the water a not unpleasant aromatic taste and odor.

Moderate numbers gave a somewhat unpleasant sweetish and oily taste and odor, and the oily and unpleasant character became more prominent as the number of organisms increased, becoming fishy and even offensive when high numbers were present. The offensive taste and odor were most noticeable in the case of water which had passed through the distribution system, and was due to the disintegration of the Chlamydomonas.

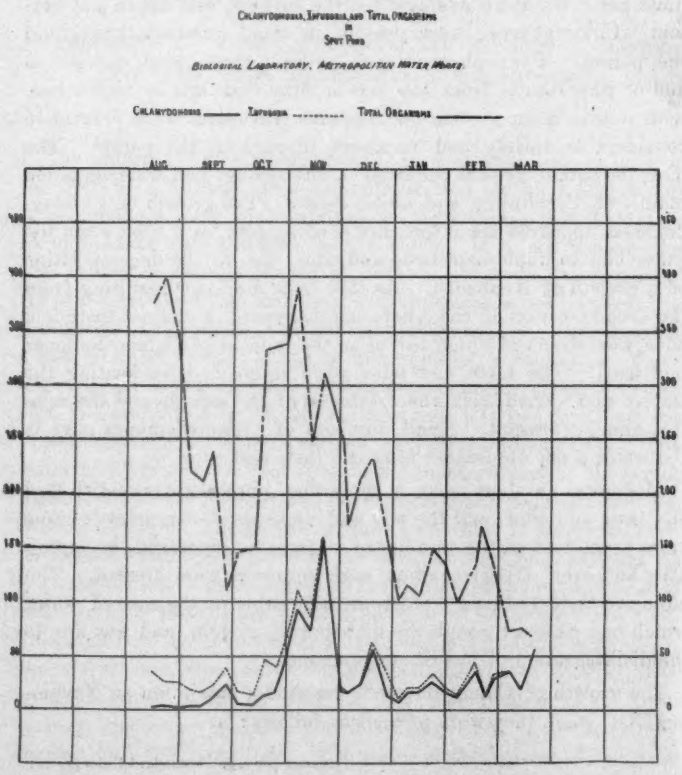
The growth of Chlamydomonas reached a maximum on November 21st, when they were present as follows:

	Number per c. c.	Standard Units per c. c.
Spot Pond—Surface	628	156
Mid-depth	682	171
Bottom	532	133
Average	614	153

Since then the growth has been confined mainly to the surface, and the average for all depths has risen only on one occasion

above fifty standard units per c. c., the average being about twenty-five standard units per c. c.

The relation between the total organisms, total infusoria and Chlamydomonas, as shown by the average for surface, mid-depth and bottom, is given on the following diagram:

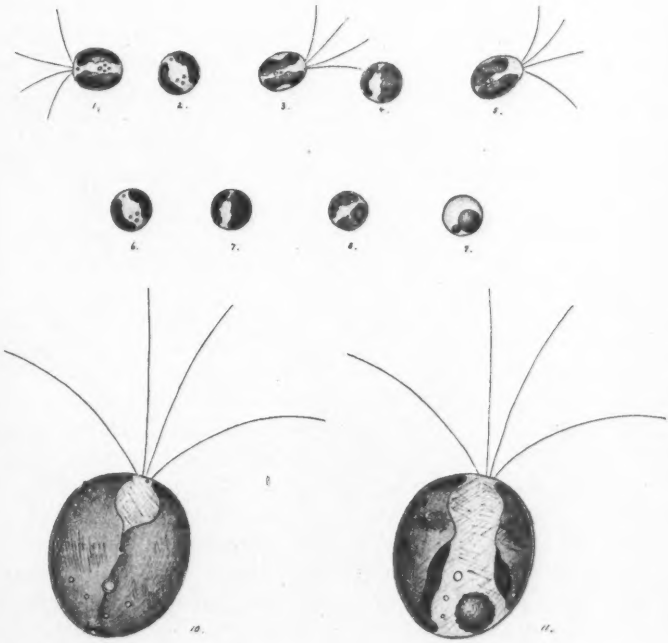


The form Chlamydomonas belongs to the class of flagellate infusoria. It was discovered by Ehrenberg in 1833 and described in 1838 in his "Infusions Thierschen" under the name of Chlamydomonas pulvisculus.

The study of the growth in Spot Pond was commenced in No-

Chlamydomonas. Spot Pond.

Biological Laboratory. Metropolitan Water Works.



vember, when measurements and drawings were first made. It is an ovoid form, having long diameter about 14 microns and short diameter about 12 microns, although different individuals vary in length by from 2 to 3 microns. It is characterized by the presence of a divided chromatophore enclosed in a lorica, although at times the portions of the chromatophos appear to be nearly fused together, and the separate parts are indicated only by an indentation toward the flagellate end (fig. 10). In other cases the individuals show the chromatophore separated far apart throughout the entire length, (fig. 11) which is undoubledly the condition preceding incistment or formation of the resting stage. The different phases of the division and arrangement of the chromatophore are shown by the small figures on the plate. Two, three and four flagella have been observed on the different individuals studied, but when three were observed, they were generally so placed as to indicate that a fourth was originally present. The contractile vacuole is situated in the clear portion at the flagellate end, and the nucleus, which is not always well defined, beyond the middle from this end. A red eye-spot is situated in the forward portion of the chromatophore, but is not seen in all individuals. Pyrenoids, described as starch grains, and clear globules, undoubtedly of oil, are present to the extent of from two to eight, arranged about the chromatophore, beyond the nucleus. The formation of the ripe zygote or final resting stage has not yet been observed beyond a doubt in this growth. The form observed in Spot Pond varies in some respects from that described by Ehrenberg. In the condition in which the chromatophore is divided, this form resembles the variety alboviridis of [1]Bütschli and of [2]Blochmann and, in some of its phases, it agrees with several of the nine forms given more recently by [3]Goroshankin as species. By watching from day to day the development of the organism, it seems not unlikely that many of the forms heretofore described as species represent different stages of development of the same organism. With the present state of our knowledge of the form, we would prefer to designate it as the Chlamydomonas of Ehrenberg.

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1. O. Bütschli. Brown H. G. Klassen und Ordnungen des Thier Reichs Leipzig.
2. Kirschner und Blochmann. Thierwele ahl. 1. Protozoa Hamburg, 1895,
3. Proceedings of the Society of Natural History of Moscow, 1891.

DISCUSSION.

THE PRESIDENT. Professor Sedgwick, will you say something to us on this subject?

PROF. SEDGWICK. I really don't know enough about it, Mr. President, to discuss it. We have had such a feast of novelties in the papers presented by the gentlemen who have come after me that it seems almost too much of a good thing. I cannot help wishing we had spread them out a little thinner, and had one paper at each meeting, perhaps; but, after all, it is very nice to have such an abundance.

I think what Mr. Hollis has said about the food material in Spot Pond is rather surprising, and it seems to me that the organism of which he speaks, or almost any other, might get all the food it wanted there. I should like to ask him if any bacterial determinations have been made?

MR. HOLLIS. Very few have been made, not enough to give us reliable averages. The five or six determinations that have been made during the past year show comparatively low numbers of bacteria; from 100 to 300 per c. c. in the pond water, and lower numbers in service pipes supplied from this source.

PROF. SEDGWICK. It seems to me that the time is coming when we have got to take up, in connection with other organisms, the ordinary water bacteria as vehicles of food. There is no question that some of these infusoria feed upon the bacteria, and there is no doubt that the bodies of the bacteria furnish food for other organisms. Now that we are getting down to a real study of the food supply of organisms in reservoirs and trying to eliminate it, we cannot much longer neglect systematic bacterial examinations as to numbers and as to kinds. That has never been carried out at great length in Massachusetts. It has been undertaken in Ohio and in Connecticut, I think to some extent, perhaps in other states more or less. It is the most difficult and unsatisfactory part of the whole problem in a way, because bacteria are so small, and because they do not occur when they ought to, and our methods are not what we wish they were; but, at the same time, from these papers that have been read this afternoon, from Mr. Jackson's valuable account of the possibility of eliminating the food for these organisms, provided we know what the food is, it seems to me we cannot much longer afford to neglect the bacteria as food carriers. Not that they are

disease germs, or anything of the kind, but they are one form of food for various organisms, and one form in which organic matter exists and scatters itself abroad. I believe that the next step in this whole subject is extended investigation on the line upon which Mr. Jackson and Mr. Whipple and Dr. Hollis and Mr. Parker are at work, adding every possible item of information in regard to the food elements, the phases in which the food exists, its quantitative and qualitative relations, and the like; and that many of these further developments have got to come from a more careful study of the bacteria.

RELATIVE APPLICABILITY OF SAND AND MECHANICAL FILTERS.*

BY GEORGE W. FULLER, CHIEF CHEMIST AND BACTERIOLOGIST, COMMISSIONERS OF WATER WORKS, CINCINNATI, OHIO.

Mr. President and Gentlemen of the New England Water Works Association: In the present state of the development of sanitary science there is clearly recognized by sanitarians the necessity of providing by municipal water departments and water companies a water supply which shall be practically free from disease germs, and which shall be satisfactory with regard to its appearance.

To discuss a proposition like this before men who are so familiar with this problem is of course out of the question; but, in passing, it is gratifying to note that as the years go by the public are showing a clearer appreciation of the situation, and more and more there is being made a study, especially in the west, of the task of procuring proper authority, and of taking other necessary steps in order that works leading to purification may be constructed. The water works official, as I look at these matters, has an important duty to perform in educating the public and in making them see this situation with all its consequences with regard to the health of the community. Among other duties of the water works official, in many cases at least, is the consideration as to the best method of purification applicable to the local water supply.

The problem of water purification is a broad one. This is of necessity so, owing to the wide variations in the geological formation and local conditions of the watersheds, resulting in marked variations in the composition of the different water supplies. To appreciate this more fully, consider, if you will for a moment, the wide variations in the composition of the river waters of this country. Here in New England we find streams, most of them short when compared with the western rivers, coming from the

* Stenographic report of Address made on Feb. 8, 1899.

granite hills, and not from limestone and clay formations; so that as they reach the cities they are normally free from those large amounts of silt and clay found in the west. They contain sewage in many cases, as is true of many western rivers, but they are radically different with regard to the matters suspended in the water from the larger streams in the west. There we find during the frequent and long-continued floods large amounts of silt, such as occasionally occur in the east, but less frequently and in smaller quantities; and in most instances there are uniformly present noticeable amounts of clay particles, which vary widely not only in size but quantity. Between these combinations of certain but varying amounts of silt, and of certain but varying amounts of clay, there is almost an endless series of different compositions of western waters, frequently varying day by day and hour by hour. To determine the best method of purifying these water supplies is not a simple matter in many instances; and, furthermore, it is rendered none the less perplexing by the fact that there are now before the attention of water works officials and engineers two well-known methods of water purification. To speak of these two methods in general terms is perhaps all that I shall be able to offer to you this afternoon.

The announcement of this meeting states or implies that we have for consideration the topic of filtration, dealing with sand filters and mechanical filters. At the outset I wish to modify somewhat the point of view implied therein, and point out further that it needs a system of purification, in a great many instances at least, to purify adequately a water supply. By that I mean that a filtration plant which would serve in a great many cases to purify properly a water supply, especially New England waters, would fail by itself, independent of the particular method of filtration adopted, when we pass to many of the waters of the west.

In these remarks I therefore wish to make use of the expression "system of purification." In this sense, the terms "sand filters" and "mechanical filters" become inadequate. In that section of the country where I have been engaged for several years on problems of water purification, it has been the custom to refer to these as the "English system of purification" and the "American system of purification." In some of the water supplies on the Ohio and Mississippi rivers there is first necessary a preliminary subsi-

dence in order to remove the grosser suspended particles. There is also necessary the use of a coagulant for the clay particles, forming them into masses of considerable relative size. Afterwards comes the question of filtration.

I desire to outline very briefly the scope of the work which has been done, and the evidence which is now available upon these two methods or systems. Taking first the English method, we find that it is now seventy years since an English filter was first constructed in London. Since 1829 a great many improvements have been introduced with regard to the construction and operation of the type of filters in use at that time. Their use has extended from England over on to the continent to many continental cities, and, where their water supplies are purified by this system, this method, speaking in general terms, has been a satisfactory one, giving a good quality of water under favorable conditions of construction and management, and at a reasonable cost.

So far as we are able to learn, the limitations of this system of purification in Europe, from evidence which is quite well defined, are comparatively small. There seems, however, to be some reason to believe, as one passes from the western portion of Europe towards the east and comes to that part of the continent where there is much more clay in the soil, as in the eastern part of Germany and in Russia, that there is encountered a class of waters where the effluent of the English type of filter, even where the water has been treated by preliminary subsidence, is so turbid, that in those places this method of purification is not thoroughly satisfactory. As one passes into Russia, there is some evidence which has been obtained in an informal manner, which shows that there may be very serious objections as to the applicability of this type of filters assisted by subsidence for the waters of the eastern portion of the continent of Europe.

All of you are doubtless familiar with the history of the English system of purification in this country. It was first studied carefully, as you well know, by the late Mr. Kirkwood, in connection with the water problems at St. Louis. The investigations of water problems here in Massachusetts, owing to the well known studies by the Massachusetts State Board of Health, have shown that for this particular class of waters, like the Merrimac River water, this method of purification is peculiarly applicable, and one which gives

satisfactory results under proper conditions of construction and of management of filters, and without preliminary treatment by subsistence.

Clarification of the water is necessary in many of the western streams. As one passes from the New England waters and the glacial drift formation, and comes to the limestone and clay formations, there is encountered a type of water much different from these New England streams, as we have already noted. Taking the Mississippi or the Ohio, there is found a river made up of a large number of tributaries, which drain geological formations more or less unlike in character and represent territory in which the glacial drift formation is a comparatively small portion of its area, perhaps in some instances entirely lacking. The result of this is that, when the heavy rains come, there is obtained a water in these large streams which is very variable in composition, carrying at times of freshets enormous quantities of silt and of clay. The character of these clay particles is quite surprising to those who have never studied them. It is found upon careful examination that their size is very small indeed. In fact, they are less than one-tenth of the size of the bacteria; that is, many of them are not more than one one-hundred thousandth of an inch in diameter.

To purify a water of this class is an entirely different proposition than to purify a water such as that of the Merrimac River. That of course is due to a number of reasons; and obviously it is due in part if not principally to the immense number of minute clay particles. We find, as the evidence steadily accumulates with regard to the applicability of the English system to American water supplies, that there are limitations to it. There are limitations in two directions. In the first place, there is the marked turbidity, in the treatment of clay-bearing waters during freshets, of the effluent of English filters, and from the English system of purification involving therein a preliminary treatment of the water by subsidence to the limit of economy. The second point in which the English type of filter is not wholly satisfactory refers to the question of the deep penetration of these clay particles into the sand layer. It is obvious that the second of these limitations leads to more expensive conditions in the operation of these filters, involving deeper and more frequent scrapings in many instances than is normally the case

abroad, and in all probability to the reconstruction of the sand layer down to the underdrains at more frequent intervals.

Relative to the limitations to the applicability of the English system of purification, they have been known in a general way for many years. At the time that Mr. Kirdwood's book was published, now some thirty years ago, the evidence was almost entirely lacking; but it is said that he made some experiments, after the publication of his book, in which he encountered some of these difficulties, but under conditions and to a degree which are not very clearly known. He especially found out the difficulty in removing the clay particles by the English type of filtration, following the subsidence of the water and the removal of the grosser particles. This point, so far as I am able to learn, was first mentioned in the literature on the subject by the late Prof. William Ripley Nichols, in the annual report of the Massachusetts State Board of Health for 1874. In an article in that report, he pointed out clearly the difficulties which were encountered, not here in New England, but elsewhere, in getting a clear effluent from clay-bearing waters by this system. The question of the deep penetration of the clay, with its complications with regard to the operation of the filter, and especially the more difficult and expensive handling of the sand layers with regard to scraping and renewal, was demonstrated first at Louisville by Mr. Hermany, chief engineer of the water company there, by experiments conducted for about eight months during 1884–85.

The question of getting a satisfactory effluent by the English type of filter in the case of silt and clay-bearing waters after a preliminary treatment and removal of the grosser particles has been studied at Cincinnati. In fact, during the last year this question has been looked into with perhaps more care than anywhere else up to this time so far as it relates to river waters carrying large quantities of minute clay particles for comparatively long periods at a time. There have been investigated a large number of conditions associated with the construction and operation of filters, and involving studies of some fifteen experimental filters, which were described in Engineering News during last December. I will not take your time to go into the details already known to you. It is sufficient to state that very early in that work there was found a confirmation of the statements as to the limitations in the applicability of the English system of purification in western waters, where conditions as you

have noted are very different from those which have been encountered here in these New England waters, especially as they have been studied at Lawrence in connection with the Merrimac River. Furthermore it was found that when the effluents continued to be very turbid for some time the bacterial efficiency becomes reduced.

The causes of the limitations in the applicability of this type of procedure are not as well understood as might be. Primarily it is due in part to the minuteness of the clay particles. There are a number of supplementary theories in explanation of it. We find, for instance, as one of the probable factors among others in explaining why the clay passes through the filters and interferes with the scraping and operation of the filters, that it is largely due, so far as we can learn, to the absence of organic matter which forms a coating, more or less gelatinous in its nature, at the top and upper portion of the sand layers. In the western waters, the organic matter is not probably so great in amount as in eastern streams. I mean those portions of it which are capable of uniting with the sand grains and forming a gelatinous coating, and thus making conditions favorable for the retention of bacteria and of the minute clay particles in suspension which penetrate and pass through the sand layer. Those organic portions of the constituents of the water seem to be not only less marked in western than in eastern waters; but at times of freshets, when the need of this action in the English filters is greatest, it appears to be most lacking then, and practically speaking, almost absent. We find, in operating English filters on the Ohio River water, that the organic matter in the water is so stable for the most part that it is not readily converted into the form of nitrates, although the conditions favoring nitrification exist there. This was proven very clearly by the fact that after the filters had been temporarily stopped for some time, there was marked evidence of nitrification in the first portion of effluent when the filters were placed in operation again. The process does take place, but so slowly that it becomes eliminated from the factors of practical significance, because the organic matter contained in the water is very stable. The probable reason why the unstable portion of the organic matter in the Ohio River water —such as we find in the Merrimac River water, and which is desired in the filter to form this gelatinous film at the surface—is largely removed, is on account of its becoming attached to a con-

siderable degree to the sand and silt of the river water, which are eliminated largely by subsidence in the stream itself and in the subsiding basins. Thus it is removed before the water reaches the filters.

The problem of finding an applicable method for those western waters is one which involves a more comprehensive study of this problem of purification than is true in many localities; and in the course of the work at Cincinnati it was found necessary to make studies of several preliminary procedures in the system of purification, of which the English filters formed the last step. To do this there was instituted during the summer, after the experiments had been under way for some three or four months, a departure substantially as follows: The water was taken at the entrance of the experimental works in practically the same condition as it left the river, and subjected to a preliminary subsidence for about three days, in which the grosser particles were removed; and then at the times of freshets, when the amount of clay was very large, there was added to the subsided water a coagulant to get the remaining clay particles massed together, in such sizes and of such specific gravity, so that they could be subsided quite readily. By a coagulant is meant any chemical capable of aggregating clay particles into masses of relatively large size. Sulphate of alumina was used in the tests spoken of. This system, known in Cincinnati as the modified English system consisted, therefore, of a preliminary subsidence of the river water, then the application of a coagulant to the subsided water at times of freshets, and provisions for the supplementary subsidence of the coagulated particles, and finally the application of the water thus treated and clarified to the English type of filter. This process, or system of purification, has been one of the important lines of investigation at Cincinnati in connection with the purification of the Ohio River water for the new water supply of that city. This effort to make the English system of purification applicable not only to the fairly clear waters of the east, but also to the clay bearing streams of the west, is one which, so far as I know, has been looked into carefully there for the first time. The matter of making the English system applicable to all types of water is one which involves, of course, factors of costs; and they in turn are dependent very largely upon the frequency with which the heavy freshets occur, causing the water

to be laden with large amounts of silt and clay. It is these circumstances, among others, which makes a knowledge of local conditions an important if not indispensable element in the practical study and satisfactory solution of all problems in connection with the English system as well as the American system of purification.

Before taking up the question of the relative applicability of these two systems of purification, I shall touch briefly upon the American system. As you well know, this system of purification is one of American origin, and one which is perhaps better known to you as the method of mechanical filtration. In all cases the application of a coagulating chemical is required before the water is filtered rapidly through sand; and in many cases subsidence is necessary as a preliminary procedure. It has been called the American system of purification by many, and perhaps that term is less confusing on the whole. However, I am not here to advocate that nomenclature for others. It is the one which I use for convenience and explicitness. The American system of purification, having its origin largely in connection with industrial enterprises for the clarification of waters, is one which now has received somewhat careful study in a few localities, especially in connection with the clay bearing streams. Experience with such waters shows that the American system is capable of yielding an effluent satisfactory with regard to appearance and bacterial contents, and owing to the carbonates of lime and magnesia in waters coming from limestone regions, there is no probability of danger from undecomposed chemical (sulphate of alumina) passing into the filtered water when the operation of a plant is in the hands of competent persons. As many clay bearing waters require, in connection with the English type of filtration, a coagulant at times for the further clarification of the water before such filters become applicable in this connection, the popular and ordinarily unfounded prejudice against the use of chemicals is common to both systems.

While the English filter is peculiarly applicable to the waters of New England, which are free from clay, and which possess organic matter to form a gelatinous film, these waters in the west, carrying large amounts of clay, and sufficient alkaline compounds in solution, are more adapted to the process of the American system of purification, which is peculiarly applicable to them, as compared with either English filters or the English system of purification. That

is so, not only with regard to obtaining a clear and satisfactory effluent, but also with regard to the economy, under ordinary local conditions, there. Comparing the American and modified English systems for western waters, both are applicable, because it is necessary in those clay bearing streams to apply a coagulant in the preliminary treatment of the water independent of the style of filtration. The cost of purification approximates the same in these two methods, but the higher rate of filtration with the American method apparently makes it somewhat more economical.

With regard to the applicability of the American system of purification to those waters which are free of clay, that is a matter on which I am not able to speak in very definite terms ; and, so far as my knowledge goes, the evidence is not very well defined along some important lines. This is especially so with regard to the amount of sulphate of alumina necessary to be added in the preliminary treatment of the water prior to filtration, and with reference to the available alkaline compounds to decompose this chemical. Those matters are ones which to my mind will require further study in connection with the clear waters of this section. Whether it will be ever found that the American system is the more applicable for the clear waters of the east is a question remaining for the future. But, in general terms, the present indications are against it. To speak of it in specific terms, of course, at the present time is practically impossible owing to the great influence which is exerted upon the various factors by the local conditions, by the cost of the filters themselves, and other factors involving the questions of the size of the plant and the management thereof.

Speaking of the two systems of purification—to sum up in a very few words, what may be used perhaps as a basis for a discussion by the gentleman following me, and bearing directly upon the subject of these remarks—it is my belief that with those non-clay bearing waters, such as are found in the New England States, the English system of purification, or as a rule English filters independent of the subsiding reservoirs, are the more applicable ; and wherever the cost is equal or cheaper, with proper construction and operations, the English system of purification is unquestionably the superior. There are, on the other hand, in the far west those clay bearing streams where the amount of clay and the frequency and duration of freshets are such that the American system of purifica-

tion is not only somewhat cheaper—that varying, of course, under local conditions and with the intensity and frequency of the freshets—but it is also a system capable of more easy management than is the case with the English system when it is necessary to use a chemical in connection therewith. That is to say, the American system is managed with more ease than the modified English system which I have outlined to you very briefly in connection with the Cincinnati investigations.

Now between these two extreme types, with the fairly clear waters of the Atlantic sea board on the one hand, and those clay-bearing streams of the far west on the other, there is a large number of streams which carry clay for a small portion of the year, and perhaps only in small amounts at any time. Between those two types, there are a great many possibilities as to the composition of the water. It looks to me as though for many of those streams either one of the two methods would be found capable of purifying the water in a satisfactory manner. And the more applicable one will be chosen only after a careful study of the local conditions, especially of the river water itself with regard to the amount of suspended matter carried by it, the variations in those amounts in different portions of the year, and the character of the suspended matter, especially in connection with the cost of preliminary procedures which have for their purpose the preparation of the water to a degree where it can be successfully filtered.

Taking up the question of filters proper, independent of the system of purification involving coagulation and subsidence, it is my belief that at the present time the science and art of filtration, so far as it relates to the English filter and to the American filter, has reached such a point that there is no longer reason for hesitancy in our opinion with regard to their practicability.

As I look at these matters, the question of selecting a suitable system of purification for any municipal water supply involves for the most part a study of that particular supply in question, and especially the preliminary procedures which may be required prior to filtration proper. In some instances, no preliminary procedures will be needed, in others, both preliminary subsidence and coagulation, and even supplementary subsidence may be necessary. To decide upon a system, which has for its preliminary portions of the process such devices and such conditions that they will be adequate

at all times to prepare the water for filtration, and, on the other hand, not to get devices and preliminary procedures which shall be too expensive, seems to me to be where the real problem comes in the future in connection with the introduction of systems of water purification. Of course, here in New England, where a majority of the members of this Association live and are connected with water departments, the problems are very much less difficult than they are in those clay-bearing regions where the streams carry large quantities of clay such as I have been speaking to you about at some length.

The question of the management of systems of purification is a point about which I wish to speak a few words. I believe, as a result of my experience, that there is no municipal system of purification, no matter how uniform the composition of the water may be, nor how apparently simple in operation may be the system of purification, I believe there is no system of purification which can be managed to advantage by any other than skilled persons. By that, I do not mean necessarily the expert, but one who understands the local conditions, and is able to meet the various exigencies which are bound to arise. I believe that for the safety of the community such a procedure, that is to say, an efficient management of the plant is absolutely necessary, and that with any system of purification without it, it is questionable whether it is justifiable to expend large sums of money, and still have it an open question whether at all times the system of purification can be depended upon. As you pass from the simple systems of purification, such as are required in this section where the variations in the character of the streams are comparatively small, to those rivers of the central west where the variations are very marked, the question of efficient management is even more important; and it can be stated in unqualified terms that no system of purification can be made applicable to those waters unless it be under the management of skilled persons. The management of such works by skilled persons is not such an expensive matter, because with their knowledge of such affairs, it is possible for them to save money in many ways. Where coagulants are to be used, it is so easy to put in excessive amounts in the purification of large supplies, it is very probable that the most skilled manager that it is possible to get would really prove in the end to be the cheapest.

In concluding the brief comparisons in connection with these two methods or systems, the question of making a preliminary study of the particular water supply, and of getting properly adjusted in the system of purification those procedures which are required, if at all, to put the river water in such a condition that it may be satisfactorily filtered, and to manage the system as well as to construct it in an efficient manner, I believe to be the most essential features with regard to successful water purification.

I wish to thank you gentlemen, for your attention in listening to these few remarks.

DISCUSSION.

MR. ALLEN HAZEN, New York City. *Mr. President and Fellow Members of the New England Water Works Association:* I have a report of progress to make today, and I am glad to say that the progress has been substantial. It has come through the work of such men as Mr. Fuller, who has just spoken to us of the interesting experiments which he has been making; of Mr. Clark, who was to have been with us today, but who is unfortunately detained; of Mr. Knowles, of Pittsburg, who is not here, and of Mr. Copeland, who is here, backed up by the most valuable experience of other members of the Association who have filter plants in their charge, and who are able to secure results of the highest importance.

The progress which can be reported today is the solution of two of the most difficult and important questions which have required attention in connection with filtration, namely, the bacterial efficiency of mechanical filters at high rates and with the use of coagulent, and the adaptability of sand filters without coagulant to the treatment of extremely muddy waters.

As Mr. Fuller has told us, sand filters have been used in England and in this country for a certain class of waters for many years and with the greatest success. We have known for a long time that these filters could be depended upon to remove the bacteria or disease producing qualities of water with certainty. They have not been used extensively for the filtration of extremely turbid waters, and we have not known how far they could be depended upon in removing these excessive turbidities, especially from the waters of the larger rivers of the Middle States, which are entirely different in their character from most of the waters which have been so treated.

As Mr. Fuller has told us, mechanical filters have been developed almost entirely in America. They have achieved an obvious and signal success in removing turbidities from muddy Western waters. There has been but little information regarding the bacterial efficiencies which could be obtained from these filters, and especially as to the results which could be obtained in removing the disease producing qualities from sewage polluted but comparatively clear waters. Some light was thrown upon this question by experiments of Mr. Weston at Providence some years ago, and more recently by some experiments at Lorain, Ohio, but these experiments were very limited in comparison with those which have been carried out at Louisville, at Pittsburg and at Cincinnati, the results of which have been, or are about to be published, and which have formed the basis of the statements which Mr. Fuller has made to us today.

As a result of these experiments, and of observations which have been collected from various sources, there is now a large amount of adequate and reliable data which will allow many questions to be solved with confidence, which until now have been most perplexing. As Mr. Fuller has told us, for the clearer waters of the New England states, and of the states bordering upon the Atlantic coast, sand filters are much more efficient, and are also often more economical than mechanical filters. The removal of bacteria by them is more complete and more certain in every way than the removal of bacteria by mechanical filters. On the other hand, with the extremely muddy waters which are found in other parts of the United States, the clarification which can be secured by mechanical filters, with the aid of sulphate of alumina is more complete than can possibly be obtained by any system of filtration without the use of coagulant.

The range in the character of the waters in different parts of the country is very great. Mr. Fuller has told us something about it. I think it might be put even more strongly than he has stated it. With the waters of New England I think it is safe to say that the average suspended matters do not form 1 part in 100,000 of the water by weight. In many streams there are much less than that amount. That would cover the suspended matters in the Merrimac, and perhaps approximately those in the Hudson. The water of the Alleghany River at Pittsburg carries an average of 4 or 5 parts of suspended matters in 100,000, and at Cincinnati Mr. Fuller tells

me that the suspended matters are 20 or 25 parts in 100,000, and at Louisville 35 parts. That is to say, the Ohio River at Louisville carries more than thirty times as much suspended matter as the ordinary river waters of New England.

Mr. Fuller has examined the suspended matter microscopically, and finds that it is, in considerable measure, made up of particles not more than an hundred thousandth of an inch in diameter, or not more than one-tenth of the average size of water bacteria. One can readily see that the processes which remove these clay particles to best advantage may be quite different from those best adapted to the removal of bacteria. The clay particles are not only smaller, but they differ in other respects. The bacteria have the power of sticking together, and of sticking to the sand particles, and in filtration they are held back in this way. The clay particles apparently have not that power, and to remove them successfully they must first be gathered together into aggregates and removed as such. This is the first condition of the successful treatment of very turbid waters. It is accomplished by the use of sulphate of alumina or other coagulant, and after it is accomplished the water can be filtered either by sand filters or mechanical filters. The essential thing to be borne in mind is that it is necessary to coagulate the particles and to remove them as aggregates instead of as individuals.

A very important point to be borne in mind in determining upon the treatment of a river water is that the character of the water in the same stream often fluctuates to an enormous extent from day to day, and sometimes from hour to hour.

In studying this question we have found a record of the turbidity of the water most useful. The turbidity of a water is determined by taking a small platinum wire, fastening it into a stick and putting it into the water of the stream, pushing it down as far as the wire can be seen and noting the depth. The turbidity is then recorded as 1 divided by the number of inches at which the wire can be seen. The wire used is 0.04 of an inch in diameter, and must be kept bright. Observations are best taken in the middle of the day and in the open air, in no case under a roof, and not in direct sunlight. The stick can be graduated directly with the proper scale, so that the turbidity can be read from it without computation.

The process is very simple, and can be put into the hands of engineers at pumping stations, or of watchmen, and observations

can be taken which are reliable, and which allow good comparisons to be made of the character of water at different times and at different places.

In small streams, flowing from water-sheds which yield clay freely, the turbidity may increase a hundred fold in the course of an hour. That is to say, the water of a stream which had a turbidity of 0.02 before a summer shower, may have a turbidity of 2.00 directly afterward. Where the wire could be seen for 50 inches before the storm it can only be seen half an inch after the storm. These fluctations, especially in small streams, are very rapid, and it thus happens that a process which is best adapted for a given water part of the time is not suited for the treatment of water from the same source for the rest of the time, and it is necessary to change the method of procedure, or else to adopt means which will avoid the use of the most turbid waters.

This brings us back to the old English practice, as old at least as filtration, of having storage reservoirs to carry the water works by periods of excessive turbidity without drawing from the stream. With small streams this is practicable and advantageous. The periods of turbidity are usually of short duration, and the water between them is comparatively clear. A reservoir used in this way will result in securing a raw water for filtration freer from suspended matters than can be secured by any practical amount of sedimentation. The improvement in the average quality of the water which can be secured in this way is very great. This procedure has been used to a limited extent in American water works, and much more extensively in England. I feel strongly that there is room for a much more extended application of it in this country.

The cause of turbidity in streams is principally the action of sharp rains upon ground under cultivation. A water which flows from grassy or wooded areas is comparative clear. The turbidity of the water from a plowed clayey field is something enormous. The water in any water course results in a mixture of the most turbid waters from the cultivated land and the clearer waters from other land, and its character depends largely upon the condition of the water-shed from which it flows. Generally speaking, turbid waters are produced only during heavy rain storms. At other times small streams are always comparatively clear.

When the turbidity is once in a water it usually follows it down to the mouth of the stream. So far as I can find, the removal of turbidity by sedimentation in streams hardly exists except in cases where there are large lakes through which the water passes. On the other hand, the erosion of the stream bed rarely exists to such an extent as to increase materially the turbidity.

Of course it is true that rivers are picking up and moving about the sediment in their beds, but the matters thus moved are not to be confused with turbidity. The particles which figure in these movements are larger than those which constitute turbidity, and such matters will be removed from the water by even the shortest sedimentation, and have no influence whatever upon the treatment necessary for its clarification.

The length of time during which the water of a stream remains turbid appears to be in direct proportion to the length of the stream, and in a general way, the duration of turbidity is approximately equal to the time required for water from the most remote feeders of a stream to reach the intake at the rate of flow which exists during a moderate flood. If the stream is of such length that the water from the most remote feeders will arrive at the intake in 24 hours, then the ordinary period of turbidity will be about one day, and will occur as often as there are heavy rains, or once in ten or fifteen or twenty days. If the stream is twice as long, the ordinary period of turbid water will be increased to about 48 hours, but the frequency of turbid periods will remain as before.

As the length of the stream increases the length of the turbid periods also increases, until, when the stream becomes so long that the time required for the water to flow to the intake from the most remote feeders reaches the average length of time between rains, the mixing becomes so complete as to give very long or practically continuous turbid periods.

This results in the curious fact, that other things being equal, the longer a river the more turbid the water seems to be. Generally speaking, a water is most turbid when the volume of flow is greatest, and in a river receiving many tributaries, the character of the tributaries bringing in the most water, and therefore in general the most turbid, is a controlling element in the character of the mixed water. With tributaries so distributed that their flood waters reach the intake successively, the turbid periods are increased in length,

and although the whole of the water is no more turbid than the water of the individual feeders, the water taken for water works purposes becomes constantly more turbid as the size of the stream increases. It is probably largely for this reason that the water taken for water works purposes from the Ohio at Louisville has more suspended matter than that taken from the same stream at Cincinnati and very much more than at Pittsburg.

This has an important bearing upon the use of storage reservoirs to carry water works by turbid periods. With short streams the advantage of such reservoirs is most marked. With larger streams the turbid periods become longer, and the clear water periods between them shorter, until a point is reached where it is no longer possible to pump sufficient comparatively clear water in the intervening periods, and to store it to supply the demand during the turbid periods. The waters of large streams are thus more difficult to treat, and the improvement which can be effected by means of reservoirs is less. The problem of filtration thus becomes doubly difficult.

One of the most interesting experiments mentioned by Mr. Fuller is that of filters upon what he calls the modified English type, or what I should call sand filters operated with the occasional use of coagulant, the coagulant being employed when the raw water is particularly bad. By this process full advantage is taken of the wonderful power of bacterial removal of sand filters, a power which is independent of the use of coagulant, and which cannot exist in the more rapid mechanical filters, and at the same time full advantage is taken of the clarifying power of sulphate of alumina at such times as the condition of the water renders it necessary. This process I think opens up a most promising field. I do not know that any works have been constructed upon this basis as yet, except that it has been used to a limited extent in some of the Dutch water works. It should be cheaper in operation under many circumstances than mechanical filtration because sulphate of alumina is only required during the turbid periods, which are often but a small fraction of the total length of time; while it has the advantage of greater certainty of bacterial purification which the sand filters possess, and without their disadvantage of being unable to cope with extremely muddy waters.

The whole matter as developed by the recent experiments may be briefly summed up as follows: Mechanical filters with sufficient sulphate of alumina quantities are able to effect very fair bacterial purification, but sand filters are decidedly superior in this respect, and are also more economical where the raw water is not too turbid and other conditions are favorable. Sand filters are able to completely clarify moderately turbid waters, but with the most turbid waters of many of our rivers, they are inadequate and fail to yield effluents of the necessary clearness. For such waters satisfactory work can only be obtained with the use of some form of coagulent, and water so coagulated may be applied to either sand or mechanical filters, as may be best for the existing conditions. In any case, a raw water with as good a character as possible should be applied to the filters, whether sand or mechanical, and to this end preliminary processes of sedimentation, storage, and, where necessary, coagulation should be developed to their economical limits in all cases.

NOTE. Following, a number of lantern slides showing plans and photographs of a number of American and European filter plants were shown.

THE PRESIDENT. Mr. FitzGerald has consented to say a few words upon this subject, and show a few lantern slides.

MR. FITZGERALD. Mr. President and Gentlemen. At the request of the President, I came here to say a few words about one or two of the plants built by the city of Boston for the filtration of water. What I shall say is entirely without preparation, and I hope you will pardon any shortcomings. I am sorry to say that Mr. Clark has been taken sick, and I have come here simply to take his place. I have been very much interested in Mr. Hazen's remarks; and I was very sorry that I was not able to be here in time to hear Mr. Fuller. I have recently come from the south, and can appreciate what Mr. Hazen says with regard to the turbidity of the rivers there. Within a few days I was called to examine an aqueduct which was built to carry river water. In the morning the water was comparatively clear, but while I was gone to get a rubber suit and some rubber boots, a rain came up, and when I returned to go into the aqueduct, it was about half full of muddy water. The color of the streams is very beautiful from the aesthetic, but hardly so from the water-works point of view. I can think of nothing nearer than a good orange color, when I look at the surface of southern rivers after a rain.

Our problems here in the east are very different from those of other parts of the country where mud and silt are carried by the water. The filter-beds at Pegan Brook and Hopkinton Reservoir are interesting in that they were constructed to filter water through the natural ground.

Pegan Brook, of unsavory fame, is one of the feeders of Lake Cochituate. When I first became acquainted with the Boston Water Works, this brook was running literally as black as your hat. I do not think I ever saw a filthier stream. Of course, the first work was to get all the drainage and sewage out of the brook; but even after that was done, the wash of the streets rendered the water of a character hardly desirable for a water supply, so that it was decided to filter it. The shores of the lake are of sand. In fact, almost all the land around Lake Cochituate is clear sand—all except the hills which are of unmodified drift. Framingham particularly is situated in what is called "The Great Sand Plain" by geologists. You can secure good mortar sand almost anywhere without any screening whatever. The preparation of the beds consisted in removing the surface soil and putting it into low embankments, and then pumping the water from Pegan Brook onto the stripped surfaces, and allowing it to percolate slowly down to the water-tables and so into the lake. Of course, beds formed in this way give the advantage of a large area at very small expense, and excellent filtration follows. We have five filter-beds. The area of the water-shed is about a square mile. The chemical analyses show that the albumnoid ammonia is decreased from .04 to practically .007.

In the case of the Hopkinton Reservoir, there are some interesting points. Just below the dam is a large area of gravel, which seemed to have been placed there by nature in the right position for purposes of filtration, and it simply required the removal of the top soil and putting it into embankments to form filter-beds. As you know, the water stored in our reservoirs has a color generally of, say, from .60 or .70 on our scale, and while the quality is excellent in every way, yet it is very desirable to get rid of the color. The area of the land was about twenty acres. Five beds have already been built, and three of them have been underdrained in order to increase the capacity of the beds.

Those who have had experience with underdraining know how very difficult it is to keep sand out of underdrains. I have seen them taken up again and again full of sand. It seems sometimes difficult to keep water out of drains, even if they are laid with cemented joints. The old-fashioned way was to put muslin around the joints. I thought I would try some new methods at Hopkinton, and tried three different methods of putting in the underdrains. One consisted of laying 12-inch split pipes, true to line and grade, and with cemented joints. Inside of these inverts 3-inch pipes were laid and covered with stones and gravel screened to form a filter. This material was arranged in three layers, putting, of course, the coarsest particles of the gravel directly over the smaller pipes, and then filling to the top of the 12-inch pipes with the finer material. The object of this invert was to prevent the water from washing sand into the underdrains from underneath. By this arrangement we had a continuous filter over the drains, so that no water can possibly get into the pipes without passing down through the filter. This has worked very well, and is an excellent way to lay them.

There is another way that Mr. Brooks designed, which we tried, and which also works well. This consisted in laying one pipe inside of another and breaking joints—a 3-inch pipe inside of a 6-inch pipe—and filling the space between these pipes with screened gravel stones about the size of a pea. It is somewhat difficult to get the filtering material into the pipes, and we had to devise special methods for doing it. The third way in which we laid the underdrains consisted in laying an invert of graded filtering gravel and then bedding the pipe. Over this was put an arch of filtering material. Each of the drains was thus covered with a continuous filter. This method also works quite well. I am at a loss to state which one of the three methods is the best. Time alone can tell, but I am partial to the first, laid with the split pipes.

There are many water works all over the country where this kind of construction is applicable, and can be put in at small cost. I do not think we resort often enough to filtration in water supply systems. My views have been expressed so many times in regard to the benefits of filtration that it is not necessary to dwell upon them at this time.

In speaking of filtration, of course there are no rules which are applicable to all waters alike. I remember very well when the Lawrence experiments were first made, everyone thought that the intermittent system was to be the panacea for all woes; but in carrying on a continuous and intermittent filtration side by side for several years, I found that the continuous gave as good results for Boston water as the intermittent, and I suppose there is little doubt now, if water has plenty of oxygen in it, that it does not gain much by an intermittent over a continuous process. There are many places where water may be diverted from the bed of a stream to a gravel area and allowed to filter through the ground where the soil is of a suitable character for this purpose, and then collected.

NOTE. Mr. FitzGerald exhibited a number of lantern slides of sewage filter beds.

PROF. WILLIAM T. SEDGWICK. Mr. President and Gentlemen. I will take time to say one word. It seems to me that this Association is very much privileged to hear from two such masters of the art as Mr. Fuller, and Mr. Hazen, in one afternoon. I am sure those who have followed the development of the whole subject, as some of us have from the beginning in this country on a large practical scale, feel very much indebted to them for the work they have been doing, and the clear and admirable manner in which it has been presented. I could not help feeling as Mr. Fuller was speaking that, with our present knowledge with regard to water, his point is good, and that we should speak of purification in general, and not filtration.

Perhaps I may say we should speak of the treatment of water rather than purification, because sometimes it is not purification, from a sanitary point of view, but treatment, as for instance, the reduction of hardness. That does not concern us much in this part of the country, but we will hear later as to the difficulty of getting a good drinking water, on account of its hardness; and processes for water softening are coming into use, and the art of correcting this is reaching such a stage of development that we can no longer take raw water and give it to the community with impunity. Treatment may require additional means for getting rid of the turbidity, but finally we may need to soften the water, and as we go on, we shall very likely find that other steps may be required to be taken. To speak of the treatment of water, is such a complete revolution

from our old fashioned American point of view that it is quite noteworthy. It is not so long ago that water companies had only to stick a pipe down into a water course and take water out with impunity. Now we are not satisfied with this. The whole process is developing. Mr. Hazen spoke very truly when he said that he and Mr. Fuller were making a report of progress. I had hoped Mr. Copeland might be here to say something on the bacteriological side of this question, but the hour is so late there is hardly time. I think this Association should congratulate itself that it has had at its tables these men who have come out into the world, taking up new problems and solving them successfully. It seems to me that *distinguished* success and ability in life is not merely to do well things which have been already done, but to go to fresh fields and take up new problems and master them. Any one who has seen Mr. Fuller's volume, knows how masterly the work is. It ought to be a source of gratification to this Association that instead of going away from home to learn the news, the news comes to us, not through a reporter, but from the investigator himself, and that we have heard from Mr. Hazen's own lips of his magnificent work; showing throughout, good sense, skill in construction, and knowledge of bacteriological work. It seems to me that we, who have seen these young men develop into men of full years, and to full activity, may well be very proud. I, at any rate am proud, and I am sure the whole Association is. I have esteemed it a favor to have been able to listen to these men this afternoon, and to come in close contact with them. This is the work that tells, and will give to America a reputation in all our future work in this connection. I think the Association is honored by having heard from these gentlemen this afternoon.

ORGANISMS WHICH CAUSE UNPLEASANT ODORS AND TASTES IN WATER SUPPLIES.

BY PROF. W. T. SEDGWICK,

Professor of Biology, Massachusetts Institute of Technology.

[*Read March 8, 1899.*]

Mr. President and Fellow Members of the Association: Your committee or officers who had in charge the preparation of programs for your meetings this season, have taken large subjects, and have suggested in their notice in regard to them that they would be treated partly on the historical side, and partly on that side which may be called up-to-date. It seems to me best to start the subject of to-day at the beginning, treating what is ancient history, however, very lightly, and giving opportunity for those who are to come after me, and who are in the very thick of the fight, a chance to tell us the latest researches and developments in this particular line. I shall then play the part of what might be called the back number in a file of magazines, and undertake to bring the subject up to the time when the numbers shall be more fresh and interesting, and I promise not to detain you very long.

If a hole should be dug in the ground and filled with distilled water, the latter would almost immediately become, relatively speaking, impure. From the surrounding earth it would receive into solution certain organic and inorganic substances contained in the soil or sub-soil, and into suspension certain other materials derived from the same sources. From the air it would receive dust, rain or snow, and these all contain materials some of which would pass into solution, while others would remain in suspension.

Now, this is very much what happens in the genesis of public water supplies. Water distilled from the earth or sea passes as aqueous vapor over the land. It is condensed in the atmosphere as distilled water, and sooner or later falls upon the earth; but long before it has reached the earth it may have been contaminated

by dust, and even by the bodies of micro-organisms. Arriving upon the earth or upon bodies of water such as lakes or ponds, it brings with it, then, not only dissolved organic and inorganic matters, small in quantity, to be sure, but nevertheless real, but also the bodies of living and probably also of lifeless organisms, few in number in some cases, but by no means inconsiderable. Even at the very beginning of a supply of surface water, therefore, the conditions are favorable for the growth of organisms, for not only are these present in their actual living forms, but food also awaits them in the dissolved or suspended materials derived from the air or from the neighboring surface of the earth. The latter in particular contributes liberally to their support, because it is itself not only highly organic, but rich in microscopic life, and if the raindrop which falls into a reservoir has, as is usually the case, either flowed over the surface of the living earth for some distance or made its way a little distance within the living earth and then again to the surface, it has derived from these excursions, in connection with the rich stores of organic matter which they contain, material suitable for the support of innumerable micro-organisms.

It may not be known to all of you, but often rain and snow, probably even when formed very high in the atmosphere, are already contaminated; I do not mean infected, but that they often contain the bodies of micro-organisms. In fact, we know from physicists that a raindrop probably cannot form even in a high atmosphere unless it forms around a particle of dust. And what is dust? Dust is ordinarily pulverized earth. And what is earth? Why, it is the surface layer of this globe, which is generally heavily charged with living micro-organisms. A particle of dust, therefore, may contaminate or pollute, if you choose to use the word in the broad way, a raindrop or snowflake at the very instant of its birth, high in the atmosphere. Moreover, as the raindrop and snowflake filter down through the lower layers of the air, richer in micro-organisms than the upper air, they take up on the way living material. This is particularly true with snow. At the end of the big snowstorm of a month ago, we collected from the top of a building on Trinity Place, in the Back Bay, snow which presumably had fallen late in the storm, and therefore when the air was comparatively free from dust. Nevertheless that snow, when melted, yielded per cubic centimeter an average of 8 or 10 bacteria

—living bacteria. A snowflake, as you can see, as it comes zigzagging down, is like a piece of cotton wool, and it naturally picks out of the atmosphere any dust particles which may be there. These living particles which are present are not necessarily wholly bacteria; occasionally microscopical organisms are found. So, also, rain, which as everybody knows often has a peculiar taste, may contain dust, and may be, as I say, impregnated at the start with the germs of life. Of course the moment it arrives on the earth it comes in contact with rich supplies of food, and with numerous other organisms than those it already contains. It is well known that when snow goes off in the spring it contributes to the rivers and the lakes vast numbers of micro-organisms; and every thirsty boy who has eaten snow knows that snow has a distinct *taste*, and that it isn't the flat taste of distilled water, but is, rather, a dirty taste in many cases; and in fact snow is very often dirty, especially in the early part of a snowstorm. And the same thing is true, of course, in a rain storm, though in less degree.

Now, my point is, that even if distilled water were to be put in a hole in the earth, it would almost immediately take up from the living earth, which is largely organic, both suspended and dissolved materials; the dissolved materials would be inorganic as well as organic, and thus food is prepared or made ready for the organisms almost at the very beginning of collection of water.

It has long been recognized that surface waters are apt to have peculiar tastes or odors. The terms "pondy," "vegetable," "fishy," "grassy" and the like, excite no surprise when applied to such waters, and it was doubtless the early recognition of these various tastes and odors, combined with the general flatness and the color of surface waters, and the liability of the latter to disappear when most needed, in times of drought, which led our ancestors to prefer and to depend upon ground water supplies, such as wells, for their drinking water. It remained, however, for the development of the microscope to make it possible for us to study satisfactorily the living population of a pond or lake, and it is a rather curious circumstance that it is only within a score of years that anything like a careful scientific examination of lakes and ponds has been begun. Such investigations arose from two sources: first, from the practical side as relating to the bearing of tastes and odors upon the quality of drinking waters; and, secondly, from the

purely scientific pursuits of biologists of the problems of microscopic life, and particularly embryology. On the former, the practical side, the State of Massachusetts was the first to begin. On the other, the more theoretical side, the work was begun by the Germans under Hensen, of Kiel.

It had long been the custom of embryologists to collect the microscopic life of the sea which swims at the surface by means of skimming-nets, the material thus collected containing, especially if taken at night, vast numbers of embryos suitable for the study of development. Hensen extended the idea of swimming embryos, hitherto known as the "pelagic" life of the sea, to include all forms of life capable of being caught by a fine net, and to such life gave the name of "plankton," a word derived from the Greek and meaning "wandering." The net in question was generally dragged over the side of a boat, and large amounts of water could thus be more or less perfectly filtered in a very short time. This method is not only of great interest in biology, but has been used by certain biologists for the examination of fresh water lakes with good results in this country, particularly in the case of Lake Mendota in Wisconsin, Lake St. Clair and Lake Michigan. It has not yet been applied to any great extent to the examination of water supplies. As a result of the immense development of biology which has taken place in the last twenty-five years, laboratories or stations for investigation have been established not only at various points on the sea, as at Penikese, by the elder Agassiz; Newport, by Mr. Alexander Agassiz; at Woods Hole, Massachusetts; Beaufort, North Carolina, and several points on the west coast of America; but also at numerous places on the Continent of Europe, and in one case, at least, in Japan. These in turn have given rise to fresh water biological stations for the study of the life of lakes and ponds, the first one dating from 1891. These stations, together with the physiological and chemical investigations of the lakes of Switzerland, have given rise to a new science, limnology, or the science of lakes, which deals not only with the lakes as physiological bodies, but also with their geology, their chemistry, their geography, their biology, their meteorology, and the like, and the relations of these to each other. In a series of lectures before the Lowell Institute, Professor George Darwin of Cambridge, England, dwelt at consid

erable length upon tidal phenomena in lakes, particularly as these have been worked out by Forel in Switzerland.

Quite apart, therefore, from all studies of lakes as sources of water supply, the last ten or fifteen years have witnessed an extraordinary development of our knowledge of lakes and ponds in various directions, so that if nothing had ever been done on the subject of lakes and ponds as water supplies, we should still be in possession of much valuable information in regard to them from the biological and limnological point of view.

As it happened, however, at the very same time when Hensen was developing his ideas of the plankton and the examination of the microscopic life of the sea by the methods just referred to, it became no less desirable to investigate the microscopic life of lakes and ponds used as sources of water supply, and in 1887 the State Board of Health of Massachusetts began their investigation of the inland waters of Massachusetts, which has constituted the basis of all investigations in America on this subject since that time. This work was at first in the hands of Mr. (now Dr.) G. H. Parker of the Museum of Comparative Zoology of Harvard University, and much valuable and interesting work was done under his direction. It became necessary for Mr. Parker to devise a method which should be somewhat quantitative, and he did this by tying a cotton cloth over the lower end of a glass tube through which the water could be filtered. For nearly two years this method was used in the work of the Board, after which it was superceded by an early form of what is now known as the "sand" method. The latter, with various improvements, has been used ever since; i. e., for about ten years, and Mr. Goodnough. who follows me, will give some idea of the results obtained by its use. It has also been employed in other States than Massachusetts, and in other investigations than those connected with the examination of water supplies—such, for example, as the study of the food of fishes by the late lamented Professor Peck of Williams College.

Since the last meeting of this Association there has been published by Mr. George C. Whipple, who is well known to us all as a graduate of the Massachusetts Institute of Technology, and as formerly Biologist to the Boston Water Works and the Water Works of Lynn, and now Biologist and Director of Mt. Prospect Laboratory, Department of Water Supply, Brooklyn, New York,

the most important volume on "The Microscopical Examination of Drinking Water" which has yet appeared in any country. A copy of this I have in my hand. The publication of this volume may be said to mark an epoch in the study of the organisms in water supplies which produce unpleasant tastes and odors. I desire to give a brief analysis of the book with a view of pointing out its fundamental importance, and in the hope that I may induce you all to buy it for your professional libraries. The author is entitled to much, at least, of recognition on the part of all who are really interested in the science of water supply, which, as you know, underlies its practical applications.

Many of you undoubtedly have seen the book. I say it is the most important book on the subject which has yet appeared. It is the only book which is in any respect whatever up to date. It is the only book in English on the subject since 1875. In that year a book entitled "The Microscopical Examination of Water" was published by J. D. Macdonald, an Englishman, but his method of examination of water was very defective. It consisted simply in collecting some sediment and looking at it. It cannot be called quantitative at all, and it was too primitive to be of very much value. It was an interesting episode in the development of the subject, but hardly anything more. This new book, prepared by Mr. Whipple, who was himself prepared by the work of the State Board of Health of Massachusetts, and that branch of it which has been followed up by the Boston Water Board, and who has been further prepared by most careful studies of his own, really constitutes a landmark in the development of our knowledge of the "Microscopy of Drinking Water," which is the title of the book. It is published by Wiley of New York.

Starting out with a description of the various methods which have been used in the examination of drinking water, the author goes on at once to the object of the microscopical examination, the interpretation of analyses, and the use of the microscopical examination in indicating sewage contamination, in explaining chemical analyses, in explaining and determining the odor and turbidity of waters, and incidentally in the studying of the food of fishes. He then enters into the details of the method described in and used throughout the book, namely, what I have called the "sand" method; points out the errors involved and compares it with other methods,

and concludes that for water works people it still remains the most useful method. That has been disputed by some and will be disputed by others. It is held, for example, by Prof. Kofoid of Illinois that the method is inaccurate to such an extent as to seriously invalidate its worth; but Mr. Whipple, after having examined the various methods, on the whole concludes that it is still the most available at any rate for the purposes represented by the members of this Association. A rival method is, as I stated, the plankton method of dragging a net through a large amount of water and getting whatever is collected by the net. It is hardly necessary to say that in such a case a great many of the finer organisms escape, and a great many of them are crushed.

Mr. Whipple then takes up the subject of micro-organisms in water from different sources, rain water, ground water, river water, canals, and speaks of *Raphidomonas* in the Lynn water, pond water and the like. Next follows a chapter on limnology, which is written, it seems to me, with a good deal of discrimination. Mr. Whipple has read widely, is familiar with the investigations in Switzerland and elsewhere. He takes up the question of the diathermancy of water, its permeability to light and the like, the temperatures at various depths, the classification of lakes, the bleaching properties of colored waters in the light, turbidity, transparency, and so on—a very valuable chapter. If all the rest of the book were to be lost that chapter would still remain of great practical value to anyone in charge of a body of fresh water which is liable to vary in color—which is sure to vary in color if a surface water—and which is liable to be invaded by micro-organisms. He then takes up the geographical distribution of the latter and their seasonable distribution, points which are not yet clearly understood, by any means, and indicates with a great deal of care the things which are known, differentiating them from those which are unknown.

At length he comes to the subject of odors in water supplies, a subject to which he has given a great deal of study, and which he sums up, it seems to me, well. This Association will be interested to see it definitely stated in print that the famous cucumber odor of the Boston water in 1879 or 1880, which we very well remember was felt to be certainly due to sponge, was probably not due to sponge at all, but to *Synura*. Anyone who remembers the excite-

ment which the condition of the Boston water caused at that time, and the great satisfaction which was felt that the cause of the odor had been discovered, will now be interested to know, as many of course do know, that it was probably not really located at the time in the sponge, although the sponge occurred with it, but that is was *Synura* which gave rise to the odor.

The author takes up the storage of surface water, the storage of ground water, the growth of organisms in pipes, etc., speaking for instance of *Paludicella*. Here we find summed up the troubles in the service pipes in Hamburg and in Rotterdam; things which previously we have had to dig out the original papers are here put together in good shape, so that anyone can get at them quickly, and trace them to the original sources if he desires.

In other words, the first 150 pages or more of the book are a good digest of the present state of our knowledge. And when you reflect that this is the only practical book in the world on this subject, that it is the only book in English printed or professing to have anything to do with the subject since 1875, that it is the only book in the world which is at all adequate, you see how important it is. It brings the whole matter up to date as well, probably, as it is possible at present to do it, and it is, therefore, a very valuable work for all who are interested in water supplies.

As Americans, and especially as members of this Association, and many of us belonging in this State, where this whole science has really had its root and origin, we have reason to be proud, I think, of the orderly fashion in which our knowledge is now brought together.

A classification of the microscopic organisms and the description of the genera and species, so far as those are interesting to water works people next follows. A biologist might be disposed to criticise this part somewhat, but for practical purposes, and that is what the book is for, in large part the account seems to be very well done. At the end of the book are appendices with directions for practical work, tables, formulae, a very admirable bibliography, which is most valuable to anyone interested in the subject, and which on the whole I should say is carefully prepared; and at the end, a glossary. Finally, we have an index and a series of plates, which unfortunately are not colored, (to publish colored plates would be altogether too expensive) but they are soft in effect and

characteristic in draftmanship. They are carefully prepared and taken either from nature or from good authors, and they are certainly creditable. They represent, as any such plates must, a large amount of careful, painstaking work; and I hope that the time may come when the sale of this book and similar books will be so extensive that the publishers and author may see their way clear to provide colored plates, which would add very much to the beauty, at least, of the work, and I think also to its practical value for waterworks people.

In conclusion, I wish to bring your attention to the fundamental biological principles which underlie this subject. As I said at the beginning, if distilled water were to be poured into a shallow hole in the ground, or may I add, if it were to be emptied into a little depression of the surface, in which it could stand as surface waters do in reservoirs, it would not long remain as distilled water. From the earth and from the air it would collect a certain amount of dissolved and suspended matters and would become what we call a surface water. Among the matters thus collected would be active or inactive but yet living micro-organisms, the smallest of which, and probably in the first instance the most abundant of which, would be those microscopic forms which we call bacteria. Immediately the bacteria would begin to multiply upon the dissolved organic matters present, and upon the bacteria would very quickly be found feeding organisms for which they are acceptable food, especially infusoria. At the same time, certain microscopic plants, green in color, possessing chlorophyll and therefore endowed with the property of manufacturing organic out of inorganic matters, would probably make their appearance, and upon these or their products in the long run more infusoria might develop until the water was rather richly charged with life. Eventually forms would appear capable of feeding upon the infusoria, and others, always larger, in turn upon these, until fishes or other relatively huge but scarce organisms should feed upon them.

In other words, we have the cycle of life supported very simply in this way: first an extract of the earth or of dust or of air or of something containing dissolved and suspended organic and inorganic matters. Upon these dissolved matters, particularly upon the dissolved organic matters, those microposcopic forms which we call bacteria, and which are really scavengers seeking for such organic matters,

would feed and multiply. We start, then, from the organic and inorganic matter in solution, with the bacteria. These come in first—they convert the lifeless organic mattter over into living matters which are food for other living matters. But soon, if the water stands long enough, green plants may appear which are able to live upon the inorganic matters dissolved from the air and from the earth, and by virtue of sunlight, and through protoplasm and that mysterious substance which we call chlorophyll, in ways which we do not fully understand, but which we believe to be functions of portions of the spectrum of sunlight, these green plants are able to live upon the inorganic matters and build up organic matters. If they die, their bodies furnish food for more bacteria; if they live, their bodies may furnish food for microscopic animals which feed upon them. So that given the bacteria at the bottom and the green plants alongside of them you may have more food materials built up which shall serve as food for other organisms, and others larger and larger in turn, until on the principle of the big fish eating up the little ones, we get up to the fishes.

Two things and only two evidently underlie these cycles, namely, first, organic matter in solution; and second, sunlight. If either of these be excluded the life present must before very long come to an end. In the case of ground waters, it is possible by covering the reservoirs to prevent the development of any considerable quantity of life, unless the supply of dissolved organic matter be kept up, and this supply is usually very scarce in ground waters. For surface waters, on the other hand, exposed as they are to the sunlight, this plan is not practicable, and neither is it practicable to do away altogether with supplies of dissolved organic matter. This is because the living earth is so rich in organic matter that any surface water must of necessity contain dissolved organic matter. The best we can do in both cases is to reduce these two sources of trouble to their lowest terms; which is aimed at in modern reservoir construction, first, by the process of stripping and, second, by securing as far as possible the absence of light by the use of deep rather than shallow reservoirs, though, of course, as soon as we do this we introduce other problems as to the water at the bottom of the reservoirs, which problems are familiar to you, and some of which are dwelt upon at length by Mr. Whipple in his book.

So far as the principles are concerned, this, then, is a very simple matter. When it comes to the application of these principles, as in the application of all pure science, the opportunities for variety are immense. The amounts of organic matter and the kinds of both living and lifeless organic matter in particular cases will be very variable. The amounts of sunlight will also be very variable. Therefore, the problems as to the population of the reservoir by microscopic organisms and the bacteria will also be various. Some of these will appear, I think, in the papers which are to follow.

DISCUSSION.

DR. HOLLIS. Prof. Sedgwick has spoken of the second method, known as the plankton method, which some advocate for use in the study of the micro organisms of a water supply. That is a subject to which I have given more or less thought, and I have studied many of the problems which have been worked out by that method, and it seems to me this would be a very good opportunity to say a word in regard to the two methods.

The study of a water supply is necessarily a practical one. These organisms generally grow, increase, at a certain depth or level, and a very large part of our work is in locating within quite narrow limits these growths, in order that the water drawn from the reservoir may be drawn in such a way as not to include the water containing the growths. This, we find, is best done by taking the samples from the surface, mid-depth and bottom. Frequently the growth is found near the surface, and in that case the water can be drawn from the other levels safely, ordinarily for some time; for a long period, before the organisms work their way down. Now, if the examination is made by the plankton method, we don't get an idea of the position of these organisms. The method consists in lowering down a net or drag, in all the cases about which I have read, and drawing it to the surface; collecting, in other words, the organisms in a column of water extending from the bottom to the surface at that point, and our count obtained in that way would be an average of the organisms at all depths. In that way we would gain no exact knowledge as to the position of the growth, and it would not be of the same value that the counts of samples taken at the surface, mid-depth and bottom would be.

SOME RESULTS OF THE SYSTEMATIC EXAMINATION OF THE WATER OF PUBLIC WATER SUPPLIES.

BY X. H. GOODNOUGH, CHIEF ENGINEER OF THE MASSACHUSETTS STATE BOARD OF HEALTH.

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The modern public water works, like many other great public services, is a thing of very recent growth. The first system of importance in this State was completed in 1848 for the supply of the city of Boston, Water was supplied by aqueduct companies in several other towns in the State previous to that time, but not in such abundance or under such pressure as would be deemed necessary at the present day. So that the modern system of water works dates from half a century ago. After the system for the supply of Boston was completed other cities and towns in the State began to follow the example of the chief city, but between 1850 and 1870 only 14 cities and towns in the State introduced public water supplies. Between 1870 and 1880, the growth was much more rapid and at the beginning of the latter year 64 of the cities and towns of the State were provided with public water supplies. At the present time the number of cities and towns supplied is 162 and they contain 90 per per cent. of the total population of the State. Only two towns having a population of more 3,500 are now not provided with public water works; while as many as 15, having a population of less than 1,500, are provided with such works. With the rapid increase in the demand for public water supplies and the increase in the number of works that began half a century ago, there came a demand for better information as to the quality of water and the study of the quality of public water supplies consequently received a greater degree of attention. The methods of water analysis in use when the introduction of water works first began were so crude that it is evident from an examination of the results of some of the chemical analyses of forty years ago that very little was shown by them in addition to

that which could have been learned by a physical examination of the water. New methods of analysis were in time discovered and the system used by Prof. Wm. R. Nichols in the laboratory of the Institute of Technology, in the early '70's, contained many of the prominent features of a water analysis of the present day. With the introduction of new methods of analysis, much additional information was furnished as to the quality of a water and it was practicable to make more satisfactory comparisons of the quality of different waters; but the number of sources under examination at any time was usually very small, and but few analyses were made, so that the results of the analyses were necessarily interpreted from a very limited experience, and it often happened that the significance of some of the various determinations was not appreciated.

A systematic examination of the waters of Massachusetts was begun in 1886 under an act of the Legislature giving general supervision and control of all inland waters to the State Board of Health, and directing the board to cause examinations of such waters to be made from time to time to ascertain whether they were adapted for use as sources of domestic water supplies, or in a condition likely to impair the interests of the public or imperil the public health. The examinations of the public water supplies and rivers of the State was begun in 1887, and have been carried on since the beginning under the direction of the engineering department of the board.

Careful studies of methods of analysis were first made with a view of selecting such methods and determinations as would show most satisfactorily the condition of a water. Improvements in the methods of analysis and additions to the number of determinations have been made from time to time when found necessary or desirable, but the original determinations were made with such accuracy that the results of the earlier years are directly comparable with those of today. It is therefore practicable by means of these analyses to study the condition of a large number of waters for a period of many years.

The investigation of the microscopical life existing in water developed gradually, like the chemical analysis, with the increase in the construction of public water works, but at the beginning of the investigations of the State Board of Health no satisfactory method of determining rapidly the number and kinds of organisms

in a given sample of water had been developed and the methods of analysis first used in these investigations were, in consequence of a lack of knowledge of the subject, crude and unsatisfactory. New methods of analysis were developed, however, by the biologist of the board, and for the last eight or nine years the method used for obtaining the microscopical condition of a water has not been materially changed.

Beginning in 1887 every system of water works in the State was examined by one of the engineers of the board and about 200 samples of water from as many different sources in all parts of the State were analyzed each month. The comparisons made practicable by these investigations and numerous analyses very soon showed several remarkable facts. Before the investigations were begun chemists had apparently discovered that the quantity of chlorine in a water bore some relation to the animal pollution of the water, but one of the most prominent facts observed early in the investigation was the great variation in the chlorine or salt contained in the waters from different parts of the State which came apparently from unpolluted sources. By tabulating the results of analyses it was soon found that there is a certain normal amount of salt in waters of this State, varying with the distance of the source from the seashore. The normal chlorine of unpolluted waters from the extreme western part of the State is as low as .05 of a part per 100,000, while that of unpolluted waters from sources near the seashore may be as high as 2.00 parts, or even more. A knowledge of the normal chlorine of the region from which a water is taken was therefore found to be essential to the proper interpretation of a chemical analysis.

Another prominent fact brought out by these analyses was the essential difference between a surface and a ground water, making it impracticable to judge of the quality of both in all respects from the same standpoint.

One of the most important facts shown by the earlier examinations was the deterioration of ground water when exposed to light. It was found that many of the ground waters when first drawn from the ground were clear, colorless and odorless and were practically free from organic matter, while these same waters after passing through an open reservoir were found to be turbid and offensive to taste and smell, and to contain often a large quantity of organic

matter. Microscopical examinations showed that the deterioration of the water was due to the presence of organisms in places where the water was exposed to light as in open reservoirs and filter basins. On the other hand, ground waters which were kept wholly from exposure to the light did not deteriorate at all in this way from the time they were drawn from the ground until they were delivered to the consumers. As a result of these studies it seemed evident that by keeping ground water from exposure to light, deterioration could be prevented. This conclusion has been borne out in numerous cases in which covered reservoirs have since been constructed to replace open reservoirs, and the results of the chemical and microscopical examinations have shown that water supplied from a covered reservoir remains of the same quality as when drawn from the ground.

Some ground waters which were found to be excellent when first examined have been found to deteriorate after several years of use. The principal evidence of such deterioration is the appearance of considerable quantities of organic matter and an excessive quantity of iron. Such waters are often clear and colorless when drawn from the ground, but quickly become turbid by oxidation of the iron when the water is exposed to the air. Such waters are objectionable for use in the laundry and for many other purposes on account of the iron they contain, and in some cases, sources furnishing such waters have been abandoned on this account. Such deterioration is generally found in sources drawn from ground containing organic matter in the soil such as deposits of river silt, or at places where there is a large depth of mud or similar organic matter on the surface, such as is often found in fresh water meadows. Deterioration from this cause has often been found in cases where a well or filter gallery is located very close to a body of surface water from which the supply is largely derived by filtration through the ground and appears to be due to the imperfect filtration of the water from the surface source. The condition of the iron found in the waters mentioned is not always the same. In many cases experiments made by the board have shown that it can be removed readily by filtration, but in some sources where the iron is associated with large quantities of organic matter its removal by filtration is difficult. Experiments have shown, however, that it is practicable to purify such waters and make them entirely satisfactory without using pro-

cesses that will render the water objectionable by increasing its hardness or by injuring its quality in any other way.

The information gained by experience in the investigation of many such cases has made it practicable in most cases to avoid the selection of sources exposed to danger of such deterioration.

The danger involved in the use of water taken directly from sewage polluted rivers, even though the source of pollution was located a long distance above the place where the water was taken, was also clearly proven by these and other investigations and in many places large sums of money have been expended in the construction of new works to secure a pure water at places where waters from such sources had been in use.

The examinations of brooks and rivers showed a great variation in the quality of water from such sources. Some of them were clear and colorless and contained but little organic matter, while others were deeply colored and contained usually a large quantity of dissolved organic matter. The highly colored waters flowed mostly from swampy districts and the color and organic matter were found to be largely due to the slow passage of water through swamps where it remained for a considerable time in contact with vegetable matter.

The examination of the water of ponds and reservoirs early showed great variations in the quantity of organic matter present in the different sources, and in some ponds or reservoirs there were often great variations in the quantity of organic matter in the course of a single year. The early investigations indicated that the waters of some ponds and reservoirs were apparently satisfactory at all times. Others were found to cause complaint occasionally, while in still others the quality of the water was frequently bad at certain seasons of the year. Microscopical examinations of the waters showed that where complaint was made as to the taste and odor of the water there was generally present a large number of organisms, frequently largely of a single species, and it was often found that the taste and odor of the water was probably due to the presence of the organisms. As a result of the investigations, it was found that certain organisms almost invariably cause certain tastes and odors when present in a water in sufficient numbers, while others give little or no odor to a water even where present in large numbers. In some ponds and reservoirs, the number of organisms found has always been small,

and the water of such sources has very rarely had a disagreeable odor, but it must be said that in the course of our examinations a large proportion of all ponds and reservoirs examined have been found at some time to be affected by the presence of large numbers of organisms or by a disagreeable taste or odor. It is not practicable within the space that can be devoted to this paper to present more than a very general statement as to the various water supplies that have been affected at times by excessive growths of organisms or disagreeable tastes and odors, or as to the organisms which have been found to cause such troubles.

Careful studies of organisms present in various surface waters have shown that there is in general a regular seasonal distribution, certain organisms being present in greatest abundance in certain seasons of the year. Anabæna, for instance, is seldom found in large numbers except in the late summer and early fall, and so far as I have been able to observe has seldom occurred in sufficient numbers in the colder portion of the year to cause serious trouble. Certain of the Infusoria, on the other hand, apparently grow in abundance only in the winter season. One of the most notable of these, and the organism which, when present in large numbers, probably causes more serious offence than any other which we have thus far observed in the water supplies of the State, is the organism Uroglena. It was first observed in March, 1892, when it occurred in very great abundance in the water supply of the town of Plymouth. Complaint as to the offensive character of the water at this time led to an examination by the board, by which it was found that a very large number of organisms of large size were present in abundance just under the ice of Little South Pond, close to the intake. The organisms were so large that they could readily be seen with a naked eye. The water in the distributing system at this time was characterized by a very offensive fishy or oily odor, but only very few of the organisms could be found after the water left the pond, and practically none were discovered in the distributing system. They apparently went to pieces after entering the pipes, but it was found that the organism contained an oil which evidently became diffused in the water and which was the cause of the disagreeable taste and odor.

Altogether this organism has been observed at different times in 44 ponds and storage reservoirs in the State; in some cases only

at one time and in very small numbers, and in other cases during several winters and in great abundance, making the water exceedingly offensive to taste and smell. It has also been observed in three open distributing reservoirs which are supplied with ground water. As already stated, this organism occurs very largely in the winter season from December to March or April, and is practically never found in the months of July, August or September and rarely in the months of June and October.

While the number and variety of microscopical organisms found in surface water is very great, our investigations indicate that many of these organisms are present only in very small numbers at any time, and only comparatively few of them, even when present in great numbers, are, at present at least, thought to be capable of rendering water disagreeable for drinking, but some of these few, notably those previously mentioned, Uroglena and Anabaena, have been the cause of very serious troubles in public water supplies. While a water company or water department supplying a city or town is not often exposed to direct competition in the business of distributing water, it is, nevertheless, true that other things being equal a water that is clear and colorless and free from taste or odor is far more acceptable to consumers and is capable of producing a larger net income for the works than one which is turbid and colored, or which is at times disagreeable to taste and smell. When a water which is usually of good quality suddenly becomes offensive to taste and smell, it appears from experience that serious injury to the income of the department may result. While it is pretty difficult to measure the extent of injury that may result to a water company or water department from a condition of its water which causes it to become offensive to consumers, I have heard of at least one case where a water department has found it desirable to make a reduction in the water bills on account of the fact that the water delivered to consumers became very offensive to taste and smell and remained so for a period of many weeks. The rebate in this case is said to have been as much as one quarter of the water rates, resulting in a direct loss of between $2,000 and $2,500 of the income of the works for the year. It should be added, that in this case the quality of the water was probably more objectionable than had been known before.

While this case gives a measure of the direct loss that may occur

to a water department as the result of an offensive condition of the water, there may also be an indirect loss to the inhabitants of the town in such cases, because the water of the public water supply being offensive for drinking the inhabitants generally resort to other sources of supply and much money is often expended in the purchase of spring waters. Nor does this expense fall upon those who can bear it best, because many instances have been found where the operatives of factories subscribe money for the purchase of spring water for drinking purposes in the factory in the summer season. Moreover, it appears that in those towns which are supplied with water which is always acceptable for drinking, little or no spring water is sold or used.

The question as to how to prevent water from becoming disagreeable from bad tastes and odors and as to the purification of waters which, while perhaps usually free from taste or odor, are objectionable on account of a high color and the large quantity of organic matter which some of them contain, has been carefully studied since the beginning and a large amount of information bearing upon the improvement of such waters has been obtained. The presentation of such facts as have been obtained and the discussion of their bearing upon the question of the improvement of such water supplies are considerably beyond the scope of this paper, but some of the more important points that have been brought out by a systematic examination of many waters under many and various conditions may be referred to.

In the case of ground waters, as already indicated, the deterioration of the water from these causes can be prevented by keeping the water from exposure to light and with such sources the cost of covering places where the water is exposed to light, such as filter basins and reservoirs, is not a very serious matter, but in the case of large surface water supplies taken from ponds or storage reservoirs, storing the water in the dark is impracticable and some other means of preventing tastes and odors in the water caused by the presence of organisms or otherwise must be devised.

With regard to the cause of the appearance of microscopical organisms in water, or the means preventing their appearance, very little is yet known. They appear in excessive numbers generally at irregular intervals, and without any apparent cause. The results of examinations for the past twelve years have shown that very few

ponds and reservoirs are at all times free from an excessive growth of such organisms. Experience seems to indicate that they are dependent upon a food supply found either in the bottom of the reservoir or in the water which enters it.

Storage reservoirs constructed in connection with the earlier works generally received little preparation for the purpose other than the removal of the vegetable matter above the surface of the ground, such as trees and brush, and these sources have generally furnished water of the poorest quality. It was supposed that the water of such sources would improve after the organic matter became dissolved out of the ground. In some cases improvement has apparently taken place in the water of such reservoirs; in other cases, however, no improvement was observable after several years of use. Examinations of samples of water collected from the surface and bottom of many storage reservoirs and natural ponds made possible a comparison of the quality of the water in each at various depths and these results showed that in some ponds and reservoirs the water of the bottom was very foul in the summer season, while in others its quality was about the same as at the surface. These investigations, together with observations of the temperature of the water of several lakes and ponds at various depths in the summer of 1889, showed that the water in the deep ponds and reservoirs remained stagnant at the bottom during the summer season and that in many of them there was a large quantity of decomposing organic matter in the water of the stagnant layers. With the cooling of the water at the surface in the fall this matter was distributed by the circulation of the water from top to bottom through all the water of the reservoir and in cases where there was much organic matter in the stagnant layers, the quantity of organic matter in the water near the surface of the pond was greatly increased in the latter part of October or early in November.

Continuing the temperature observations through the following year, it was found that there was another period of stagnation in the winter season and a second short period in the spring when the water circulated freely from top to bottom. In this connection, it may be of interest to quote from a report of Dr. C. T. Jackson, a chemist, employed to investigate the cause of a "cucumber taste" in the water of Lake Cochituate. The investigations were appar-

ently made in November of the year 1854, or about forty-four years ago:

"We visited all parts of the lake, tasted of the water at every tributary lake and stream, and that drawn by a hose from various depths in the lake. We found the surface water free from any unpleasant taste. * * * *

"Water drawn from a lower depth had that peculiar flavor which we find in the aqueduct water in Boston, and this taste was strongest at the depth of from 19 to 39 feet from the surface. * * * *

"We all agreed in opinion that the taste resembled that of water in which cucumbers had been soaked. * * * *

"The temperature of the water at the gate house was 43½°, that of the air being 53°. At the bottom of the lake the thermometer stood at 44°, hence the water at the bottom of the lake is a little warmer than that of the surface. The records of the superintendent of the lake show, that during the month of July last the temperature of the water was, in the gate house, 73° F. * * *

"We rode all around the country that is drained into Cochituate Lake, and tasted of every streamlet or collection of water, and did not observe in any of those waters that peculiar flavor which we had found in the deep water of Lake Cochituate. It would seem, therefore, that either the bad tasting stratum of water had entered the lake some time since, or that it has derived its peculiar taste from fermenting vegetable matters at its bottom. If the bottom water had become charged with a vegetable infusion during the heat of summer and autumn it could not rise to the surface until the top water was cooled down to such a degree as to render it denser than the water below, so as to descend and displace it. The maximum density of water is at 39.2° F., while the water at the gate house has been 78° in July and August, and is now at the bottom 44°. It is evident that if the surface water during cold nights should descend to 39.2°, that it would descend and displace the lower strata of water, and cause them to rise. This would take place at less differences of temperature at slower rates, exactly proportioned to the differences of temperature, provided the upper strata should be coldest; but the reverse could not take place, hence warm water does not descend to replace cold water, unless the temperature of the lower water should be considerable below 39.2°,

when it would be lighter, as may be seen from the following table. * * * *

"It is well known that the bad taste of Cochituate Lake water came on soon after the sudden cold weather of the middle and latter part of the month of October, and perhaps this sudden change of temperature may account for the rising of the lower strata of water, so as to cause them to run into the conduits. * * *"

In the construction of a new reservoir by the Boston Water Works in 1886, the plan was tried of removing all the soil and vegetable matter from its bottom. This reservoir was completed just before the general examination of water supplies by the State Board of Health was begun, and samples of its water, collected from the bottom as well as the surface, have been analyzed at regular intervals for many years. In this reservoir and in a few natural ponds, it was found that no decomposition took place in the bottom in periods of stagnation, and in the water of these sources, also, it very seldom happens that any considerable growths or organisms are found. In more recent years, it has been the general custom in constructing storage reservoirs to remove the soil and organic matter from the bottom, and where this work is thoroughly done and the water entering the reservoir is of good quality, and is not made up largely of ground water, it has thus far been found that the water of such reservoirs has contained but few organisms and is apparently not affected by disagreeable tastes or odors. In one case, where the most favorable site for a reservoir contained a swamp having a depth of mud of many feet, the removal of which would have been very costly, the plan was tried of covering the mud with gravel to a depth of 18 inches. The quality of the water of this reservoir has been excellent during the few years that it has been in use.

These and other studies indicate that the removal of all the soil, mud and vegetable matter from the bottom of a storage reservoir makes the water stored therein in a large degree unsuitable for the high development of microscopical organisms. The results of certain other investigations give evidence that the water of reservoirs can be rendered even more unfavorable as places of development of large numbers of organisms if in cases where the brooks and streams which enter them contain large quantities of organic matter, improvements in the channels or water sheds of the brooks could be

made which would reduce materially the quantity of organic matter in the water. In this state, the brook waters which contain large quantities of organic matter usually acquire the organic matter from standing in swamps. If it is feasible to drain a swamp thoroughly and prevent water from the uplands from entering it, the water flowing from the watershed in which the swamp is located can be greatly improved. The extent to which the improvement of a swamp by drainage may improve the quality of the water of a stream may be indicated by presenting the results of analyses of one such case, where a swamp occupying about 12 per cent. of the area of a watershed was drained in such a way that the water flowing from the uplands was intercepted before entering the swamp and the water flowing upon the swamp was quickly removed by ditches carefully constructed for the purpose. The average results of several analyses taken before and after the construction of these drains is shown in the following table :

Color.	Total Res.	Loss on Ignition.	Ammonia,		Oxygen Consumed.	
			Free.	Albuminoid.		
1.76	5.12	2.90	.0017	.0329	1.562	Before Drainage.
0.24	3.19	1.14	.0007	.0099	0.303	After Drainage

In connection with the analysis of samples of water from ponds and reservoirs at various depths, the water of the principal feeders of such sources was also examined and upon comparing the results it was found that in the reservoirs and ponds of the better class, while the water flowing into them had, in some cases, a high color and contained a very large quantity of organic matter, the water flowing out of them had less color and organic matter, showing that it had improved by standing in the reservoir.

Since storage reservoirs are usually constructed some time before they are actually needed, it is generally feasible to prepare them properly for the storage of water, but it generally happens that after the use of such reservoirs is begun it is not practicable to empty them and go without the water for a season without providing other means for supplying the city or town. In the case of a natural pond, also, it is of course generally impracticable to empty it and remove any organic accumulations from its bottom and while it is

possible that in the case of some ponds and reservoirs an improvement of the watershed may have a sufficiently favorable influence upon the quality of the water to prevent further serious trouble from tastes and odors, it may often happen that improvement in the water cannot be effected in this way.

The problem of preventing such waters from becoming offensive to consumers from time to time is a serious one, since there is a considerable number of such sources. It is possible that some means may be discovered for the prevention of organic growths in such sources, but no way of preventing such troubles is known at the present time. It is probable that such waters can be filtered in such a manner as to remove the organisms and odor without injuring its quality in other respects, and considerable information has been obtained as to the filtration of such waters and further investigations are under way.

The question is often asked as to whether waters containing large numbers of microscopical organisms, or which are offensive to taste and smell, probably on account of the presence of such organisms, are likely to be injurious to the health of those who may drink the water. With our present information on this subject, we can only say that it is not known that the presence of these organisms, or any of them, in water renders it injurious to health. The well-known fact that some of the higher plants, such as ivy and dogwood, while injuring some persons who handle them, yet have no effect upon others, suggests the possibility that a similar influence may be exercised by some of these organisms upon some of the persons who drink water containing them. Even more suggestive is the well-known fact that some fruits and vegetables, such as strawberries and mushrooms are so injurious to some people that they find it necessary to avoid their use. It is also well-known that eating decayed fruits and vegetables is very dangerous in the summer season, and it is suggested that drinking water containing decayed organisms may possibly have a similar effect. A further suggestion that these organisms may be injurious, is found in the obscure epidemics of diarrhoeal diseases that occur in the summer season when large numbers of people are sometimes attacked at the same time, while the people of another community nearby may not be effected. It will naturally be extremely difficult to determine whether the organic matter in the form of

microscopical organisms in water has an unfavorable influence upon the health of those who drink the water; and it must be remembered in this connection that very few people will drink water that is offensive or even slightly odorous, but will rather go to the expense of purchasing other waters.

As a result of the systematic examinations for many years, our knowledge of the conditions which effect the quality of all kinds of public water supplies has been greatly increased. It was natural that many important discoveries were made within two or three years after the work began, but new and very important facts have been learned from time to time, and our examinations reveal more clearly than ever the great need of further definite information upon many points. They show, also, that the regular examination of public water supplies is even more important than was suspected in the beginning. And it is probable that in the future further knowledge upon this subject will be obtained which will be at least as important as the information already acquired.

DISCUSSION.

PROF. SEDGWICK. I would like to say just one word in justice to Mr. Richards, Superintendent of the New London water supply: Before this meeting began he was telling of a case exactly similar to that which Mr. Goodnough has pointed out, where by the intercepting of the water from a watershed on its way to a swamp he was able to avoid a large amount of color, which the water would have had if it had gone through the swamp. The expedient which he adopted, seemed to me so interesting I urged him to bring it up at some future meeting of the Association, when we have experience talks, and it seems to me it would be well worth doing. As Mr. Goodnough has said, it is a simple and a very useful and effective plan, in some cases at any rate, to drain the swamp in order to prevent the standing of the water there, and in other cases to intercept the water, which would go to the center of the swamp and perhaps stand there, before it has a chance to do so; thus preventing it from ever becoming colored. The case which Mr. Goodnough has mentioned is ample testimony to the value of the practice. Mr. Richards has done this in the case of an additional supply to his New London reservoir, and with admirable results, he says; and it seems to me this is an

interesting and timely point in connection with Mr. Goodnough's valuable paper.

In regard to *Uroglena*, I cannot help calling the attention of the Association to the fact that in this connection the investigations of practical water works men have thrown great light on the theoretical side of the subject. When *Uroglena* was first detected or reported, it was found in Middletown, Connecticut, by Prof. Conn, of Wesleyan University, who did not at first recognize what it was, and thought it was another organism. That was in June, 1889, if I remember right. A little later than that it was found by Prof. Williston, in a reservoir, only a few miles away, in Meriden, Connecticut; and then it was found in great quantities as Mr. Goodnough has said, in Massachusetts, and was thought to be a novelty in both States. It has now been found in, I think he said, 44 supplies of this State. In other words, now that we have looked for it, and have had systematic examinations of the water supplies, we find that instead of its being a rare and unusual thing, it is really a pretty common thing. Formerly those who made a specialty of keeping track of the microscopical organisms from a purely microscopical point of view had not even reported it in this country. I remember looking for it at the time in a list published by some expert on the subject of Infusoria, and not finding it.

So that here practical work has developed very interesting scientific truth, as so often happens. There is no contest between pure science and practical science, between pure and applied science, and never can be. Each helps the other. Pure science gives us points for practical work; practical science reacts and stimulates the study of pure science. One has only to turn to electricity to see the exemplification of this law. It seems to me that in *Uroglena* we have also a very interesting example of it, and a very valuable one.

It ought to be a matter of pride to members of this Association that many of them have been able to follow the actual steps of progress made in this direction from year to year. And nowhere in the United States, I think we may say without boasting, and indeed nowhere in the world, has the examination been carried on so systematically. Mr. Goodnough has made a very good point there. At the start it was urged by the wise physicians and engineers who were on our Board of Health, that these examinations should be

extensive, that they should be *systematic*, that they should be *long-continued*. They have been all of these. And Mr. Goodnough testifies, and we all testify, that we to-day realize more than we ever did before the importance of keeping them up and making them thorough, for out of these researches come practical results of immense value to any one dealing with the subject.

MR. PARKER. While we are speaking of this organism, Uroglena, I should like to tell the Association a little experience I had. Some years ago I had occasion to inspect a large reservoir, which was connected with a system of other reservoirs, in reference to a particular subject. After completing that inspection I made my report to the superintendent, and three days later I went out to the reservoir to see how matters were progressing. To my surprise and astonishment I found I had an entirely new and more important problem on my hands. In that period of three days an immense growth of Uroglena had developed in the reservoir. I made a hasty examination of the reservoir, and immediately went back to Boston, and from there to the superintendent to whom I was to report. As I went into the room he was giving orders to draw water from this infected reservoir. I think if that had been done the whole supply of the city, which I had temporarily in my charge then, would have been ruined; I think for at least a period of three months it would have been impossible to have given the citizens good water.

That shows the importance of this work, and it also shows the importance of field work. It is not enough to have samples come to the laboratory. We must have the laboratory supplemented by field work, and by the observation of practical men who have the water in charge. Any man who has a reservoir, by training himself to look out for the sediment, and especially the change in color, may very often be able to give very valuable information to those in charge of the laboratory.

And in connection with this same subject, I might say that this system of reservoirs was so arranged that we could cut out this contaminated reservoir from the system and draw from the others. Now it seems to me that is a valuable point. There are a great many, or at least several towns in New England that do not depend on the supply from one point or from one body of water. They have two or three bodies of water. And if those towns employed a biologist to tell them at what depth in their ponds to draw, and

when to draw from certain ponds, all the citizens would be very greatly benefited. It isn't such an expensive matter to employ a biologist, and I think it is for the superintendents here to call the attention of the city fathers to the fact that there are towns in the State that have biologists, and to suggest it to them if it would not be well for them to employ such a man in connection with their supplies. That is one of the practical results which I think has come out of the magnificent work which has been done by the State Board of Health.

MR. HASKELL. Mr. President, I have had the opportunity to have charge of water works where we did have an opportunity to observe our water, and to draw from the source in which the water was the best. We have a laboratory, and we examine our water every week. We find there is no difficulty in telling beforehand when a certain organism is preparing to show itself. We find that it is just as readily discovered as it is to see a crop of clover grow in a clover field or oats in an oat field. And we have been able at different times to draw water from one pond, and then perhaps from another, when a personal observation of the water at the point would not have led us to make that choice. I have gathered a sample of water, and to all appearances, as I looked into it, it was the best water that we had, but the analysis showed that there was an organism preparing to develop; and in another pond, where the water looked even better, there was an organism which was disintegrating and was disappearing. So we would change, and by making the change we would get better water. And the only possible way by which we could have got the information which led us to make the change was the microscopical examination. It could not have been determined by personal observation, either by taste or smell, which of the two waters was the one which should be taken. Nobody can tell by personal observation; there must be a microscopical examination. And we have been able to give better water from year to year by having our laboratory, and understanding the proper way to detect where the organisms were going to develop; and we often change right in the middle of the week from one pond to another, neither of which is necessarily bad, but one of which is better than the other.

A FEW WORDS UPON WATER FILTRATION.

BY H. W. CLARK, CHEMIST, STATE BOARD OF HEALTH OF MASSACHUSETTS.

[*Read Feb. 8, 1899.*]

After the very interesting papers by Mr. Hazen and Mr. Fuller upon the subject of water filtration, it is rather difficult for one, whose experience with filtration has been limited to New England waters, to present anything particularly new. Yet New England experiences with New England water supplies are the experiences of most of the members of this Association, and when the water supply in which any one of you is most interested arrives at the point where filtration becomes a necessity, or is desirable, most of you will undoubtedly prefer to filter it in the tried and proved way of slow sand filtration, the method that has been for so many years in successful and satisfactory operation in England, on the Continent and at Lawrence, Mass.

Unfortunately, in one way, nearly all of the New England data upon the subject of sand filtration has been obtained at Lawrence from the experimental filters at the State Board of Health Station, and the large filter belonging to the city. The results from all these Lawrence filters are published yearly in the reports of the State Board of Health, together with more or less of the details in regard to their management.

It was found during the first years of investigation at Lawrence, that the highly polluted water of the Merrimac River could be filtered through loam and sand at a comparatively low rate and practically all the bacteria of the applied water removed. Following this, experiments were made to ascertain if water as polluted as this river water, could be filtered at rates great enough to make sand filtration practicable in connection with town and city water supplies and at the same time render the filtered water safe for domestic purposes.

These investigations were carried on with great care and thoroughness, and were continued long enough to render the results obtained of much value when applied to New England water supplies, or water supplies resembling those of New England. As a result of them, the Lawrence city filter was constructed in 1893, and even the most doubting person should be convinced of its efficiency at the present time, for here is an example of a city smitten with typhoid fever epidemics yearly when using unfiltered water that has been practically free from the disease since filtered water was introduced.

The death rate from typhoid fever at Lawrence has decreased steadily each year up to the end of 1898, since the introduction of this filtered water. It is true, as was remarked upon by a city government and water works delegation who visited us at Lawrence a short time ago, that this decrease began before the construction of the filter, but in answer to this it can be said that for a year or two previous to filtered water being supplied to the inhabitants of the city, the dangerous character of the water supplied directly from the Merrimac River was known to the more intelligent of the people, both because of their own observations and because of warning notices from the State Board of Health. Consequently, the sale of spring waters was a large and growing business in the city, the city water was in many families boiled before using, and one of the large mill corporations had constructed and had in operation for a year or two a sand filter large enough to furnish pure, well filtered water to all the operatives in its mills.

The death rate of the city in 1892 from typhoid fever, however, was 10.52 per 10,000 inhabitants—this year being the last entire year that unfiltered water was used, and the death rate from typhoid fever the lowest for many years up to that time. During the past year, 1898, the death rate from typhoid fever was 1.39 per 10,000 inhabitants, that is, there were only eight deaths in the city from this disease, including several mill operatives who were exposed at least to infection from the unfiltered canal water supplied for various purposes in many of the mills.

The rate of filtration of the city filter rarely if ever exceeds 2,000,000 gallons per acre daily. In regard to the rate of filtration that can be maintained by sand filters and still result in pro-

ducing a safe drinking water, I think that too much attention has been given to European ideas and rules regulating the rate and not enough to the character of the water to be filtered in particular cases. That is, the degree of pollution of the water chemically and bacterially, its percentage of dissolved oxigen, etc. This is a point I think that we are learning more about each year and broad statements made in Lawrence reports in earlier years we would wish to qualify to some slight degree at the present time and limit their application to certain waters and certain conditions. Thus, in the 1895 report I stated that "the longer the investigations upon water filtration continued the more evident it became that the entirely satisfactory bacterial purification of water could be obtained at rates of filtration much greater than formerly supposed. Entirely satisfactory results being obtained during 1895 from filters operating at rates of 5,000,000 and even 7,000,000 gallons per acre daily." These results, I should say at the present time, were satisfactory when bacterial efficiency alone is considered, that is, the percentage of bacteria of all kinds removed from the Merrimac River water by the filters. Four filters were operated at these high rates for definite periods, and 99.50 per cent. of the bacteria of the applied water were removed. Of course, these were experimental filters, and were handled probably more carefully than filters on a larger scale could be handled, but at the same time, there were some things in their construction which were likely to render the results obtained from them less satisfactory than from filters of a larger area. For instance, the side area of the experimental filters is much greater when compared to the superficial area than is the case with larger filters, and it has always been noticed at the station, and referred to many times in our reports, that there is a tendency at times of change of temperature for a channel to be formed between the sand and the straight sides of the experimental filters, down which some water occasionally passes to the underdrains without having passed through much, if any, of the sand.

But perhaps, as our further work tends to show, some things must be taken into consideration besides the actual percentage of bacteria of all kinds removed when we are talking about satisfactory and efficient filtration; especially so when we are dealing with a water as polluted as that flowing in the Merrimac river at Lawrence.

During the past year or two, besides the determination of the total number of bacteria present in the river water and the filtered water from the various experimental filters and from the Lawrence city filter, many determinations have been made to show the presence or absence from these waters of B. coli communis, the characteristic bacteria of sewage. This work has been undertaken to show, if possible, if bacterial efficiency, as we have designated it, meaning the percentage removal of bacteria of all kinds is directly comparable at all seasons of the year with the percentage removal of this sewage bacteria. We have believed that by the continuation of this work for sufficient time the significance of the appearance of this germ in filtered water can be determined, because of the opportunity presented of studying the full results obtained with regard to its presence in samples of filtered city water taken from various points upon the city system, together with the occurrence or non-occurrence of typhoid fever in the city. These bacterial results from the city filter we can also compare directly with the results from the experimental filters at the station operating at different rates, but receiving the same polluted river water. In doing this work we of course assume that the absence of B. coli from the filtered water is an unquestioned proof of the absence of the typhoid germ, and that its presence in the filtered water is more or less suspicious, because typhoid may at times accompany it. The typhoid germ is never found in river waters unaccompanied by B. coli, although the reverse is, of course, far from true. Just how much these investigations will show we cannot state at the present time, but that they will be of considerable value I have no doubt.

Up to October 1, 1898, of 117 samples of the filtered city water collected at the city filter and examined for B. coli, nine, or 8 per cent., showed its presence in a single colony; five of these samples, however, in which it was found were taken at the times of scraping the filter, or other disturbances of the sand. Of 119 samples collected during the same period from a tap at the City Hall after the water had passed through the reservoir and about one mile of service pipe, four showed the presence of B. coli. The bacterial efficiency of the filter during this period calculated upon the total number of bacteria removed was 99.67 per cent. This taken into consideration together with the B. coli results and the small number of cases of typhoid fever in the city during the year up to that

time, indicates, at least, that the appearance of this germ in filtered water and in single colonies is without any great significance, and it is doubtful if any of the cases of typhoid fever occurring in the city up to December 1st were due to the filtered water supply.

During the course of some work at the filter in October, November and December, some of the beds of sand were considerably disturbed, and owing to the sudden advent of winter weather were not in as good a condition as intended or expected when water was turned on after the last disturbance. Following this a number of cases of typhoid fever developed in the city. It is quite remarkable, however, that even following this period of disturbance the average bacterial efficiency of the filter did not fall below 97 per cent., but B. coli appeared frequently and persistently in the filtered water.

In regard to B. coli in river water, I noticed that in Mr. Fuller's report upon the purification of water in Louisville, he states that in 1897, 21 tests for this germ were made with samples of the water of the Ohio river, and in only three instances was it found. The difference between the Ohio and Merrimac River waters in this respect, and the much greater pollution of the Merrimac River water, can be easily seen, when I state that samples were taken from the Merrimac river on 288 days during 1898, and in 287 of these samples the germ was found. The average number present being about 50 per c. c.

I have stated that it is questionable whether we can place so much confidence in simple bacterial efficiency or percentage removal as we previously have done, for during 1898 tests made with our two largest and best experimental filters showed that while operated at rates of 4,000,000 gallons per acre daily, nearly as good bacterial efficiency was obtained as when operated at rates of 2,500,000 gallons daily, not enough difference being shown to mean much of anything to the average engineer, still the results upon the removal of B. coli were very much better at the lower than at the higher rate. Details in regard to our work along this line will be given in the Report of the Board for 1898.

I have been very much interested in the work at Louisville and Pittsburg, especially have I noticed the remarkable figures in regard to the amount of silt in the Ohio River water at all times, and

especially at times of flood and the consequent apparent impossibility of operating sand filters at Louisville.

But this turbidity is something foreign to New England rivers, except at infrequent intervals, and hence is something we do not have to grapple with.

A rather interesting experiment showing that it is largely silt and not organic matter that clogs water filters has been made at Lawrence during the past year, where we have had two filters in operation receiving water containing much more organic matter than the river water applied to the other filters, but practically no silt. This water has passed through these two filters during the entire year at rates somewhat greater than 2,000,000 gallons per acre daily, and caused no clogging of the surfaces of the filters except that which a slight raking two or three times during the year has removed.

PROCEEDINGS.

ADJOURNED MEETING.

PARKER HOUSE,

Boston, February 8th, 1899.

President Forbes in the chair.

The following members and guests were present:—

ACTIVE MEMBERS.

George I. Bailey, Charles H. Baldwin, Lewis M. Bancroft, R. S. Bartlett, George E. Batchelder, Joseph E. Beals, James F. Bigelow, Fred A. Brooks, George Bowers, Dexter Brackett, E. C. Brooks, George F. Chace, Charles E. Chandler, John C. Chase, William F. Codd, Freeman C. Coffin, H. W. Conant, J. W. Crawford, A. O. Doane John W. Ellis, Frank L. Fales, B. R. Felton, Desmond FitzGerald, Z. R. Forbes, John N. Ferguson, Frank L. Fuller, George W. Fuller, Harry F. Gibbs, Albert S. Glover, X. H. Goodnough, Frederick W. Gow, E. A. W. Hammett, John C. Haskell, William T. Haines, T. G. Hazard, Jr., Allen Hazen, Clemens Herschel, Horace G. Holden, Frederick S. Hollis, William Jackson, H. R. Johnson, Willard Kent, Patrick Kieran, Geo. A. Kimball, Horace Kingman, James W. Locke, Charles F. Murphy, H. A. Nash, Jr., Thomas Naylor, Frank L. Pierce, George S. Rice, Walter H. Richards, George J. Ries, W. W. Robertson, William T. Sedgwick, Charles W. Sherman, Herbert E. Smith, Sidney Smith, H. T. Sparks, George A. Stacy, Lucian A. Taylor, Robert J. Thomas, William H. Thomas, H. L. Thomas, D. N. Tower, William W. Wade, Charles K. Walker, John Venner, Robert S. Weston, William Wheeler, John C. Whitney, George E. Winslow.

HONORARY MEMBERS.

"Engineering News," by M. N. Baker.
"Fire and Water," by F. W. Shepperd.

ASSOCIATE MEMBERS.

Blake, The George F. Mfg. Co., by George J. Foran.
Hersey Mfg. Co., by Albert S. Glover and A. A. Blossom.
Jenks, Henry F., Pawtucket, R. I.
Lead Lined Iron Pipe Co., by T. C. Dwyer.
Ludlow Valve Mfg. Co., by W. H. Doyle.
Mueller, H. Mfg. Co., by M. G. Milliken.

Mitchell Coal and Coke Co., by J. M. Holmes and G. H. Blake.
Neptune Meter Co., by H. H. Kinsey.
New York Filter Co., by Charles Wilson.
Perrin, Seamans & Co., by Mr. Seamans.
Builders' Iron Foundry, Providence, R. I., by T. C. Clifford.
Smith, A. P. Mfg. Co., by William H. Van Winkle.
Worthington, H. R., by J. N. Chester.

GUESTS.

Alexis H. French, Mr. Copeland, J. A. Stubbs, St. Albans, Vt.; G. E. Hofmaster, Mt. Vernon, N. Y.; F. L. Weaver, Lowell, Mass.; W. F. Sullivan, Lowell, Mass.; G. A. Johnson, Cincinnati, O.; J. B. Wood. Marlboro, Mass.; H. T. McClaren, Arthur Deane.

Fred Brooks, of Boston, was elected a resident active member, and Fred G. Judkin of Franklin Falls, N. H., was elected a non-resident active member, and the Mitchell Coal and Coke Co., of Boston, was elected an associate member.

Mr. George W. Fuller, C. E., chief chemist and bacteriologist, water works, Cincinnati, Ohio, addressed the Association upon the subject, "Relative Applicability of Sand and Mechanical Filters." The subject was discussed by Messrs. Hazen, FitzGerald, Bailey and Sedgwick.

On motion of Mr. Kent, the thanks of the Association were extended to Mr. Bailey for his cordial invitation to the members of the Association to visit the water works of the city of Albany, of which he is superintendent.

Adjourned to the second Wednesday in March, 1899.

QUARTERLY MEETING.

PARKER HOUSE,

Boston, March 8th, 1899.

President Forbes presiding.

The following members and guests were present.

ACTIVE MEMBERS.

Charles H. Baldwin, Joseph E. Beals, James F. Bigelow, George Bowers, Dexter Brackett, E. C. Brooks, George A. P. Buckman, George F. Chase, Harry W. Clark, Freeman C. Coffin, H. W. Conant, Byron I. Cook, A. O. Doane, John W. Ellis, A. A. Forbes, Frank Baldwin French, Frank L. Fuller,

L. L. Gerry, Julius C. Gilbert, T. C. Gleason, Albert S. Glover, X. H. Goodnough, Richard A. Hale, John C. Haskell, L. M. Hastings, V. C. Hastings, Horace G. Holden, Frederick S. Hollis, Daniel D. Jackson, William Jackson, William S. Johnson, Willard Kent, James W. Locke, Theodore McKenzie, Frank E. Merrill, Thomas Naylor, Frank L. Northrop, Horatio N. Parker, Walter H. Richards, T. F. Richardson, George J. Ries, W. W. Robertson, Henry W. Rogers, William T. Sedgwick, George A. Stacy, Frederick P. Stearns, Robert J. Thomas, D. N. Tower, William W. Wade, Charles K. Walker, John C. Whitney, E. T. Wiswall.

ASSOCIATE MEMBERS.

Chapman Valve Mfg. Co., by E. L. Ross.
Coffin Valve Co., by E. J. Chadbourne.
Crosby Steam Gage and Valve Co., by Robert Pirie.
Henry F. Jenks, Pawtucket, R. I.
Ludlow Valve Mfg. Co., by H. F. Gould.
Mueller, H. Mfg. Co., by M. G. Millikin.
Mitchell Coal and Coke Co., Boston, Mass.
Neptune Meter Co., by H. H. Kinsey.
Perrin, Seamans & Co., by H. L. Bond.
Rensselaer Mfg. Co., by F. S. Bates.
Builders' Iron Foundry, Providence, R. I., by R. A. Robertson.
Smith, B. F. & Bros., by Joseph W. Martin.
Union Water Meter Co., by F. L. Northrop.
Wood R. D. & Co., by Mr. Newhall.

The following were elected resident active members:—

Arthur W. Dean, City Engineer, Nashua, N. H.; James W. Blackmer, superintendent, Beverly, Mass.; George Cassell, Superintendent, Chelsea, Mass.; Frederick S. Clarke, Chairman Water Board, North Billerica, Mass.; Joseph H. Linsley, director State Biological Laboratory, Burlington, Vt.

Mr. Kent moved the appointment by the President of a committee of five to nominate a list of officers of the Association for the ensuing year. Adopted.

MR. STACEY. I think the appointment of that committee is an important matter, and I would like to know if there isn't some way by which it can be provided that this committee, which is to be appointed, shall meet at some time previous to fifteen minutes before the nominations are made. That seems to have been the practice within the last two or three years, and I should like to have a limit of time fixed within which the list of officers nominated should be made out previous to the meeting at which they are to be voted on.

THE PRESIDENT. It would be my intention to appoint the committee at once, or within a week's time, and to notify them, of course,

and then they can have a meeting as soon as they can get together, or at any rate in June, when the Association is supposed to meet for one day. At that time, if the committee see fit, they can make the nominations, and their report can be made on the first day of our annual convention, if necessary. That would naturally be left with them, but the idea is to give them ample time in which to consider the nominations, and also to give the members of the Association ample time to examine the list.

MR. STACEY. That is my idea exactly; but you know, and all of the members know, what I have reference to. The committee has sometimes been appointed early enough, but when the time came to make the nominations some of the committee have not been present previous to the hour at which the nominations were to be made, and some of them not even at that time; and that is a matter I should like to see remedied, so that there will be plenty of opportunity to give full consideration to the subject. I think it is of enough importance so that the committee ought to meet and consider it and make the nominations at some time previous to the meeting at which they are going to be voted upon, and that is the reason why I have made this suggestion. I have no doubt the committee will be appointed all right, but I should like to have some provision made by which they should have a meeting and make these nominations a week or two weeks or a month previous to the meeting at which they are to be acted upon.

THE PRESIDENT. Would it not be wise, Mr. Stacey, to make a motion that this committee report at the annual meeting in June?

MR. STACEY. I will move that the committee on nomination of officers for the ensuing year report at the annual meeting in June.

MR. BRACKETT. I would suggest this as an amendment, that the list of nominees be printed in the notice for the annual meeting.

THE PRESIDENT. Will you accept Mr. Brackett's amendment, that the list be published in the call for the annual meeting and be distributed with it?

MR. STACEY. Yes, I will accept that. I understand that we shall vote for officers at Syracuse, and not at our real annual meeting in June, and if the committee reports at the June meeting, then we shall have ample time between that and September to know who the nominees are.

MR. BRACKETT. If they simply report at the meeting in June, there would not be any notice given to all the members, unless it was published in some way. My idea is that it should be published in connection with the notice for the meeting at Syracuse, when I suppose the officers will be elected.

MR. STACEY. I accept that amendment.

Mr. Stacey's motion, as amended by Mr. Brackett, was adopted.

The first paper of the afternoon was read by Prof. W. T. Sedgwick, Professor of Biology at the Massachusetts Institute of Technology, his subject being, "Organisms which Cause Unpleasant Tastes and Odors in Water Supplies." The paper was discussed by Dr. Hollis.

X. H. Goodnough, chief Engineer of the Massachusetts State Board of Health, then read a paper entitled, "Some of the Results of the Systematic Examination of the Water of the Public Water Supplies." The paper was discussed by Prof. Sedgwick, Mr. Parker and Mr. Haskell.

The next paper was one prepared by George C. Whipple, Biologist and Director of Mt. Prospect Laboratory, Brooklyn, N. Y., and D. D. Jackson, Chemist, Department of Water Supply, Brooklyn, N. Y., and was read by Mr. Jackson. The subject was, "Asterionella; its Biography, its Chemistry, and its Effect on Water Supplies." This paper was also discussed by Prof. Sedgwick.

Dr. Hollis read the last paper of the afternoon, which was entitled, "A Brief Account of an Occurrence of Chlamydomonas Alboviridis." The paper was prepared by Dr. Frederick S. Hollis, Biologist, Metropolitan Water Board of Massachusetts, and H. N. Parker, Assistant Biologist, Metropolitan Water Board.

Music was furnished at the meeting under the direction of Mr. F. L. Pratt, of Cambridge.

Adjourned.

JUNE OUTING, 1899.

The June meeting and the summer outing day of the Association was on Wednesday, June 14. Assembling near the North Union Station at about 10 o'clock a. m., electric street cars were taken for Everett to visit the extensive works of the New England Gas and Coke Company. Arriving at the works, the visitors were very

courteously received and shown over and through the various devices, plans and processes of the plant. The day was a hot one, one of the hottest of the season. As gas was the principal subject under our consideration, it might not be exactly complimentary to the young engineer who served us as guide to say that he was filled with his subject; but, as with rivulets of perspiration running down his face he answered a running fire of questions from his visitors, he seemed, at least, to be warmed up to it, and to be possessed of a well-invested stock of information on the subject. On that day the water men were not making light of it.

Through the courtesy of Mr. Whitney, the grand master of the enterprise, we are able to present the brief description of the Everett works which follows this sketch.

Escaping from the heat of gas retorts, the party was taken by the electric street cars to Reading, where a lunch had been spread in the town hall.

Lunch having been disposed of, barges were taken for a ride of some three miles to the filter plant of the Reading Water Works. This was described in a former number of our Journal by Mr. Bancroft, their superintendent.

Arriving at the railroad station, President Forbes called the members to order, and a number of new members were elected, and the meeting adjourned to Wednesday, September 13, at Syracuse, N. Y.

EVERETT WORKS OF THE NEW ENGLAND GAS AND COKE CO.

The works are located in the cities of Everett and Chelsea, and are bounded as follows:—On the south by the Mystic river; east, by the Island End river and Naval Hospital grounds; north, by the Boston and Albany railroad; west, by part of the residential section of Everett. The area amounts to three hundred (300) acres.

The plant consists of 400 Otto Hoffmann ovens, with a total daily capacity of about 2,000 gross tons of coal. It is well equipped with modern mechanical appliances for the cheap handling of coal and coke, and a complete system of condensation and purification for tar, gas and ammonia. The yearly consumption of coal by this plant will aggregate about 800,000 tons.

The coking process will give yearly in by-products, in round numbers, the following:—

627,000 tons of coke.
24,000,000 lbs. of sulphate of ammonia.
8,000,000 gals. of tar.
6,000,000,000 cubic feet of gas.

Three billions of the gas manufactured will be utilized at the works for the heating of the by-product ovens.

In the coking process, which lasts about 24 hours, the gases that first come off from the coal are much richer, averaging some 15 to 16 C. P., while the latter part of the process, the C. P. runs as low as 6 or 7.

The coal used is of poor quality of bituminous coal, and is what is known among bituminous coal dealers as "culm," or "slack."

This coal is discharged at the company's wharf, which has a discharging capacity of some 600 tons an hour, and is dumped into an elevated coal pocket, which has a capacity of 6,000 tons of coal; it is then dumped from the pocket into self-dumping coal cars, of about two and one-half ($2\frac{1}{2}$) tons capacity. These cars are operated by an endless cable, and the coal is carried up by inclined planes to four smaller coal pockets, of about 2,000 tons capacity; the coal cars return empty to the wharf to be refilled from wharf pockets. The coal is dumped into traveling larries, which are operated by electricity, and have a capacity of 6 tons each—the capacity of each oven. The coal is then dumped from the larries into the ovens, while they are at a white heat; the oven is then sealed, and nothing is allowed to escape except through the proper channels.

The coking process, as above stated, lasts about 24 hours. During this time from each ton of coal is obtained:—

10,000 cubic feet of gas.
21.96 gallons of crude ammoniacal liquor.
7.6 gallons of tar.

The first 5,000 feet of gas is taken off and sent to the condensing house, where it is thoroughly scrubbed and washed by the process familiar to all gas men. In this process the tar and ammonia is removed, and the gas is driven, by means of exhausters, into the purifying house, where all poisonous materials, such as sulphur

and CA_2, are removed, and from that point goes into the 5,000,000 cubit feet holder (which is as large as any in the country), and is ready for delivery to the various companies, who will enrich it from 13 to 14 C.P. to 18 C.P.—the candle-power required by law.

The second 5,000 feet of gas is also sent to the condensing house for the purpose of saving the tar and ammonia, and from the condensing house sent into a small holder, and from that point supplied, as needed, to what are known as regenerators, which is a system of fire-brick passages where the gas and air is mixed and a terrific heat is generated. By this means the ovens are heated.

The tar and ammoniacal liquor caught in the condensing house are run into enormous tanks, and from these points the tar, which is the heavier, is pumped into storage tanks, and from that point passed into barrels or pumped to the distilling works, which are to be erected by the National Coal Tar Company, at Everett, where the tar will be distilled, the main product manufactured being pitch.

It might be well at this point to state that most of the tar and ammoniacal liquor runs into these tanks by gravity from conduit pipes over the ovens, where they condense from the gas in its passage through the pipes.

In addition to this a distilling process will be carried on, and aniline dyes and many other articles will be manufactured.

The by-products from the distillation of tar alone comprise some three hundred different articles well known in the commercial and chemical world.

To return to the ammoniacal liquor and tar tank. The liquor is pumped into what is known as the ammonia house; at this point the ammonia is distilled off from the liquor by means of steam, and the ammonia is here thoroughly mixed with sulphuric acid, and ammonia sulphate is produced; the principal market for this article being the manufacture of fertilizers and the finer qualities of ammonia.

The coke, which of course is the main product of the works, after being thoroughly coked, is pushed from the ovens, which are open at both ends, by an electric ram, into what is known as a coke loader—a large iron traveling car. At this point it is thoroughly quenched by water, and when sufficiently cool is dumped from the loader into cars and is ready for shipment.

In addition to the above mentioned buildings and ovens, there is a large power house consisting of eight 250-horse power boilers; two 800-horse power engines, and two 400 K.W. dynamos, which furnish the electric power necessary in operating pushers, larries, loaders and tower hoisters.

The works, when in complete operation, will employ a force of 400 men; this includes a day and night shift.

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ERRATA IN SEPTEMBER, 1899, JOURNAL.

The numbers on Plates I and II accompanying the paper on ASTERIONELLA should be transposed.

Page 29, line 6 from top; for *chromatophos* read *chromatophores*.

Page 29, second foot note; for *ahl. 1* read *abt. 1*.

Page 86, line 1; insert the word *occasional*, so as to read, "that the occasional appearance of this germ," etc.

Page 87, line 6 from top; insert the word *sometimes*. so as to read, "that it is sometimes largely silt and not organic matter," etc.